Federal Technology Alert

A series of energy efficient technology guides prepared by the New Technology Demonstration Program

U.S. Department of Energy

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Residential Heat Pump Water Heaters

Energy-Saving Alternative for Home Hot Water

Residential heat pump water heaters (HPWHs) are an energy-efficient way to heat domestic hot water. Although currently only a small portion of the residential water heater market, the technology has been implemented effectively in the Federal sector in Hawaii and other Pacific islands and demonstrates some potential for increased Federal use at military bases and other Federal sites that include residential housing.

This *Federal Technology Alert (FTA)*, one of a series on new technologies, describes the theory of operation, field experience (savings and reliability), range of application, and how to evaluate the HPWH technology for a particular use.

Energy-Saving Mechanism

The HPWH provides an energy-saving alternative to electric resistance water heaters. The technology works on the basis of heat transfer, removing heat energy from a source such as room air and transferring the heat to water stored in a hot-water tank. Because less energy is needed to move heat than to create it, the effective water-heating efficiency of the HPWH system is greater than 100%.

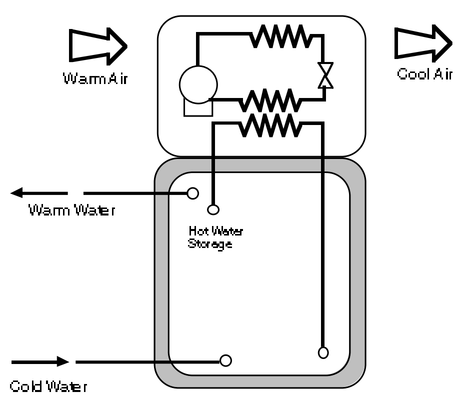
HPWHs are available both as retrofit units for existing electric hot-water tanks and as stand-alone units that completely replace an existing hot-water heater. Variations in design depend on the configuration of heat pump unit and storage tank and on whether the heat is extracted from inside the residence (ambient-air systems) or from exhaust ventilation air (exhaust-air systems). In general, ambient-air systems are better suited for warm climates. Exhaust-air systems are better suited for cool climates, particularly when mechanical ventilation is required. Both types of residential HPWH units are wired with electrical resistance backup heating units.

By heating water more efficiently, HPWHs reduce water-heating energy cost. In addition, ambient-air HPWHs can help meet air-conditioning loads; they extract heat from the air and they continually exhaust cool air as a by-product. This cool air can help reduce air-conditioning costs. In addition, HPWH units draw significantly less power than electric resistance water heaters, which may help in reducing electrical demand for some sites.

Despite the potential for high energy savings, payback periods for HPWH installations vary widely, and potential applications should be studied carefully with an understanding of the energy-saving mechanisms and the potential effect of HPWH operation on other household energy demands.

Technology Selection

Heat pump water heaters are one of many energy-saving technologies to emerge in the last 20 years. The FTA series targets technologies that appear to have significant untapped Federal-sector potential and for which some Federal installation experience exists. New



Residential Heat Pump Water Heater

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technologies were identified through advertisements for technology suggestions in the *Commerce Business Daily* and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutions, Federal sites, and other interested parties.

Technologies suggested were evaluated in terms of potential energy, cost, and environmental benefits to the Federal sector. They were also categorized as those that are just coming to market and those for which field data already exist. Technologies classified as just coming to market are considered for field demonstration through the U.S. Department of Energy's Federal Energy Management Program (FEMP) and industry partnerships. Technologies for which some field data already exist are considered as topics for FTAs. Residential heat pump water heating technology was found to have significant potential for Federal-sector savings and to have demonstrated energy-saving field performance.

Potential

Analysis of Federal residential facilities indicates there is yet untapped energy conservation potential in the Federal sector that could be met through the residential HPWH technology. Relatively high first costs and maintenance costs and relatively low energy costs throughout the Federal sector currently limit cost-effective applications of the technology. In addition, negative prior experience with early residential HPWH installations at Federal sites will be difficult for manufacturers to overcome. The technology will be most welcome in areas where natural gas is not available, where electrical energy prices are high, and where space heating energy requirements are low, either because of hot and humid climates or through the use of space heating heat pumps in milder climates.

Application

Qualitative field testing and theoretical analyses have shown HPWH technology to be technically valid and economically attractive for selected sites. However, several issues should be addressed by anyone planning to install HPWH units, including: identification of the appropriate HPWH design for the intended application, avoidance of locations where freezing could harm the system, determining the optimal use of available cooling, and determining whether there is available and adequately vented space for the HPWH and possible increased storage tank size.

Residential HPWHs are most applicable under the following conditions:

- where electricity rates are high and gas rates are high or gas is not available
- in residences where the estimated hot water use is high
- in warm climates where space cooling is important
- in mild/cool climates where there is a need for mechanical ventilation.

Use of HPWHs should probably be avoided in the following circumstances:

- where water heater consumption is low (such as in small residential units or those with high rates of vacancy)
- in mild/cool climates where electric resistance heat is used for space heat (ambient-air systems only).

Costs for residential HPWHs vary from $600 to over $2,000. In addition, installation costs for HPWHs range from $300 to $700 a unit. Anyone contemplating installation of HPWH units should check with local suppliers and/or installers and with regional utility companies for information about availability, warranties and incentive programs that may help reduce first costs for residential HPWH systems.

Technology Performance

The energy savings potential of residential HPWHs has been documented by numerous field tests, with measured efficiencies that are highly dependent on site and equipment. In general, most residential HPWHs can be expected to heat water at between two and three times the efficiency of a electric resistance water heater. However, since some HPWH designs draw on the warm room air for a heat source, the effect on space heating or cooling loads must be calculated in determining cost-effectiveness.

Maintenance costs for residential HPWHs are significantly higher than for other water heating technologies. Experience at bases that use HPWHs suggests that two hours per year should be expected for preventative maintenance activities. In addition, typical in-service life spans have in the past been lower than manufacturers' expectations, often because of faulty installation or component failure. Maintenance costs beyond preventative maintenance are largely unknown for the newest generation of HPWHs.

Case Study

A hypothetical case study from a military base in central California was developed to illustrate the process for determining the cost-effectiveness of residential HPWHs. The implementation of ambient-air HPWHs was evaluated for residential housing with an average of 3.3 persons per residence. At $0.059/kWh and $7.85/kW-mo demand, the energy costs were high for the Federal sector.

The HPWHs considered were add-ons to existing electric resistance water tanks. It was assumed that the existing water heaters had an energy factor of 0.85. The existing water tank sizes varied between 40 and 52 gallons An installed cost of $985 for each HPWH was assumed. Because the storage tanks were somewhat small, an estimate of the amount of backup electric resistance heat was made, reducing the effective energy factor of the HPWH analyzed to 2.52, down from the rated energy factor of 2.61.

Annual maintenance costs for the HPWH were estimated to be $30/residence. The HPWH life was conservatively estimated at 10 years. Life-cycle costs for the electric resistance heat alternative and the HPWH alternative were calculated using the NIST Building Life Cycle Cost (BLCC) program.

The HPWH in the above example was not cost-effective. However, examples of cost-effective applications in other locations were demonstrated using energy costs typical for large Federal sites near those locations.

Outlook

The major barriers to implementation of this technology in the Federal sector are high first cost, high maintenance requirements, and relatively low electrical energy costs. Unless Federal rulemaking mandates the use of HPWHs in all residential electric water heater applications in the near future, significant Federal use of HPWHs will probably require the development and field testing of low-cost, low-maintenance HPWH models to demonstrate that the technology has matured and can be cost-effective. Until that occurs, significant use of residential HPWHs in the Federal sector will probably be limited to the few southern U.S. and Island locations where a combination of high energy costs and low space heating requirements have made HPWHs cost-effective in the private sector.

Federal energy managers who are familiar with HPWH systems are listed in this FTA. The reader is invited to ask questions and learn more about the technology.

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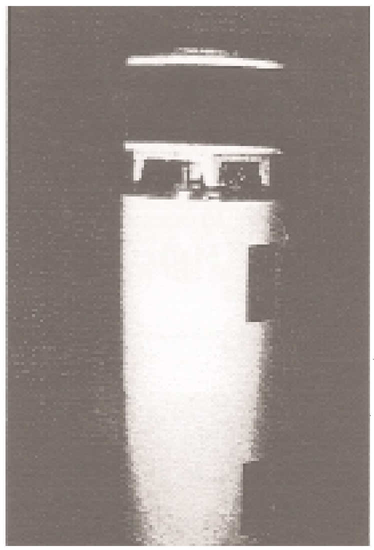
Residential Heat Pump Water Heaters

Energy-Saving Alternative for Home Hot Water



Abstract

Heat pump water heaters (HPWHs) are an energy-efficient way to heat water with electricity, typically providing the same amount of hot water at one-half to one-third the energy used in electric resistance water heaters. This FTA discusses residential-sized HPWHs. HPWHs presently comprise only a very small fraction of the residential water heaters sold in the United States. They have been successfully used in a number of Federal facilities, mostly in Hawaii and other Pacific islands. The potential for Federal installation elsewhere in the nation is highly dependent on facility energy rates, first costs for HPWHs, and local climate considerations.

An HPWH unit consumes much less electrical power than an electric resistance heater. As a result of the reduced energy consumption, utility costs go down. Other benefits exist as well. For example, some units can provide air-conditioning as a by-product of water heating. Four basic designs are manufactured; each design has advantages under different circumstances. In general, however, the technology has been shown to be more cost-effective in warm climates.

High initial costs, initial design problems, and cases of faulty installation have burdened HPWH technology with a reputation of poor cost-effectiveness. However, these issues can be alleviated through careful application screening, design, and installation, and through regular maintenance.

Laboratory testing and theoretical analysis have shown HPWH technology to be technically valid, and its performance has been conclusively demonstrated in the field. Cost-effective applications for residential HPWHs do exist, but they are limited. This FTA provides detailed information and procedures that a Federal energy manager needs to evaluate potential residential HPWH applications. Principles of HPWH operation and application are explained, and design variations are discussed as are their advantages and disadvantages in a given application. Procedures are given for evaluating heating capacity, estimating energy use and savings, and calculating life-cycle costs (LCC). Proper application, installation, and operations and maintenance (O&M) impacts are discussed. A hypothetical Federal-sector case study is presented to give the reader a good sense of what is really involved in assessing and implementing this technology. In addition, a list of Federal-sector users and a bibliography are included for prospective users who have specific or highly technical questions not fully addressed in this Technology Alert.

Contents

About the Technology

Water heaters in small, residential buildings are designed to serve one family and to operate on either gas (natural gas or propane), oil, or electricity. Currently, electric water heaters provide 38% of U.S. residential water heating needs (EIA 1990), virtually all using electric resistance coils to heat water.

An energy-saving alternative to electric resistance water heaters is the heat pump water heater. Although HPWH technology currently represents only a small fraction of the residential water heating market, it has been available for residential applications since the 1970s. One U.S.- manufactured unit, first put on the market in 1988, is shown in Figure 1.

An HPWH works by transferring heat, not by creating heat. Through a reverse application of the standard vapor compression refrigeration cycle, a heat pump water heater uses an electrically driven compressor to remove heat energy from a low-temperature heat source (ambient room air) and move it to a higher-temperature heat sink, the water stored in the hot-water tank. The energy required by the heat pump is primarily electrical energy needed to operate the compressor. The energy supplied to heat the water comes from both the heat transferred from the ambient air and the energy used to operate the compressor in the system. Because less energy is needed to move heat than to create heat, the effective efficiency of the heat pump water heater system, defined as the ratio of hot water energy output to energy input to the water heater, is greater than 100%. The effective efficiency is called the Coefficient of Performance (COP).

Field tests report water heater energy savings of 40-70% (Caneta Research 1993a) in a variety of test conditions. Payback estimates, however, vary widely: from 3 to 20+ years in residential applications. An understanding of how HPWHs save energy, how the technology is affected by environmental and load parameters, and how it in turn affects other household energy loads is vital to determining proper applications.

This FTA describes the technology behind residential HPWHs, uses the available information from manufacturers, users, and others to address issues relevant to application in the Federal sector, and explains how to determine the feasibility of residential HPWHs for a given application.

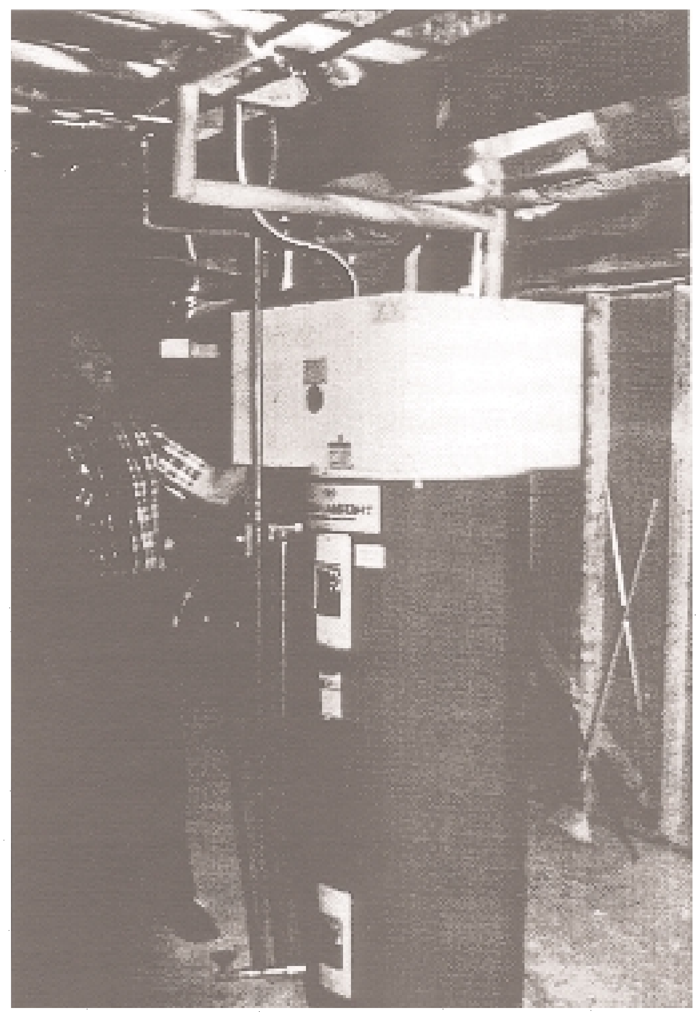


Fig 1. Heat Pump Heater with Exhaust Air Heat Recovery

Scope

This document discusses HPWHs designed for residential applications. Large (>20,000 Btu/hr output) HPWHs designed for commercial applications also exist. Although the technology behind residential and commercial HPWHs is similar, major differences exist in unit size, markets, applications, and evaluation of cost-effectiveness. A separate FTA on commercial-sized heat pump water heaters is planned.

In addition, this document focuses on dedicated HPWHs. Technologies such as heat pump desuperheaters and integrated A/C-heat pump-water heater units are discussed only as other water heating technologies that should be considered for residential housing in the Federal sector.

Application Domain

Currently, residential HPWHs make up a very small fraction of the residential water heaters sold in the United States, with less than 2,000 units being sold annually in recent years (E-Source 1994), down from a high of 10,000 - 15,000 in the 1980s (Caneta Research 1993a). A large fraction of these sold in past years went to Federal military housing in the continental U.S. as well as Hawaii and other Pacific islands. Within the Federal sector, residential HPWH could theoretically be installed in almost any domestic water-heating application. More than 100,000 residences are scattered over scores of Army, Navy, Air Force, and Marine bases around the world. To this number should be added thousands of other potential residential applications, such as residence housing for Forest and Park Services and other branches of the Federal sector, as well as numerous small commercial buildings that use residential-sized water heaters. Thus the potential for use of HPWH in the Federal sector is large, vastly exceeding the number of residential HPWHs sold annually in this country.

Although in theory, HPWHs compete for market share with both electrical resistance and natural gas water heaters, economics suggest that because of current prices for HPWHs and near-term gas and electricity costs in most of the U.S., HPWHs are seldom a cost-effective alternative to natural-gas-fired water heaters when gas is available. However, in areas where natural gas costs are high or where high-priced propane or synthetic gas is used for water heating, HPWHs may prove cost-effective.

In general, existing information indicates that HPWHs are generally more cost-effective in warm climates, especially areas where electric costs are high and natural gas is also high or unavailable. As evidence of this, HPWHs have most successfully penetrated the U.S. private and Federal residential markets in Hawaii.

HPWHs should also be considered in residences located in cool climates where there is also a need for mechanical ventilation. Some HPWHs are designed to recover heat from exhaust air from a mechanically ventilated residence. This type of HPWH is an effective heat recovery system for these residences, and as a result of this, have become common in areas of northern Europe.

HPWHs are most cost-effective in buildings where hot-water energy use is relatively high and the greater savings in hot-water energy cost can offset the higher first cost of the HPWH over other water heating technologies. Criteria for good residential HPWH application are provided later in this FTA.

HPWH units are available in both retrofit units, designed to attach to existing electric hot-water tanks, and stand-alone units, designed to completely replace an existing water heater. The respective advantages of each are discussed in this FTA.

Energy-Saving Mechanism

Residential heat pump water heaters can be two to three times as efficient as electric resistance water heaters at heating water. Moreover, they can provide space cooling as a by-product while heating household water. Typical residential units use 500 to 1,200 watts at peak load, compared with 4,500 watts or more for the most common electric resistance water heaters (E-Source 1994), and because they heat water more efficiently, they may also provide a reduction in electrical demand.

A typical residential HPWH operates by extracting heat from a moderate-temperature source (such as room air), and moving it to a higher-temperature heat sink, the residence hot-water supply. This heated water is then stored in a hot-water storage tank for later use. The physics and operation of the HPWH is identical to the vapor compression refrigeration/heat pump cycle used for space conditioning heat pumps, air-conditioners, and refrigerators. Figure 2 shows the components used in the vapor compression refrigeration/heat pump cycle: compressor, condenser, evaporator, and expansion device. The flow of refrigerant between components in this closed cycle is also illustrated.

In the compressor, refrigerant vapor is compressed, thereby raising its temperature and pressure. This vapor then moves to the condenser. In the condenser, heat flows from the hot refrigerant to water surrounding the condenser. As heat leaves the refrigerant, the refrigerant condenses to a high-pressure, liquid state. The heat removed from the refrigerant as it changes to a liquid is transferred to the water.

The high pressure, liquid refrigerant leaves the condenser at a temperature slightly above the temperature of the water surrounding the condenser. The liquid passes to an expansion device, where it is rapidly depressurized, and some of the liquid refrigerant flashes back into vapor. The vaporization of a portion of the refrigerant causes the remaining refrigerant to cool rapidly, and the refrigerant leaves the expansion device as a low-temperature mixture of fluid and vapor. This cold mixture then enters the evaporator, where it absorbs heat from air blown over the evaporator coils. The liquid portion of the refrigerant evaporates, and the vapor then moves back to the low-pressure side of the compressor at a temperature slightly below the temperature of the heat source.

This continuing cycle results in movement of heat from the ambient air to the higher-temperature residential hot-water supply.

In residential HPWHs, the heat source is typically air from inside the residence, although with proper duct design, the air could come from inside the residence, from outdoors, or can be set manually to come from either depending on climate conditions.

Electrical energy is required to operate both the compressor in the HPWH and a fan that continually blows air across the evaporator coils when the unit is operating. Depending on the system design, a water pump may also be needed to circulate water between the condenser and the storage tank. The compressor, however, is the major electrical load in an HPWH. Most of the energy consumed by the compressor is used to compress and subsequently heat the refrigerant vapor, with only a small fraction of energy lost as heat from the shell of the compressor. Since the total energy to the hot water comes from the energy transferred from the heat source as well as virtually all the energy that is used by the compressor, the net amount of heat energy transferred to the hot water is considerably higher than the net input of electrical energy by the compressor. In residential HPWHs,

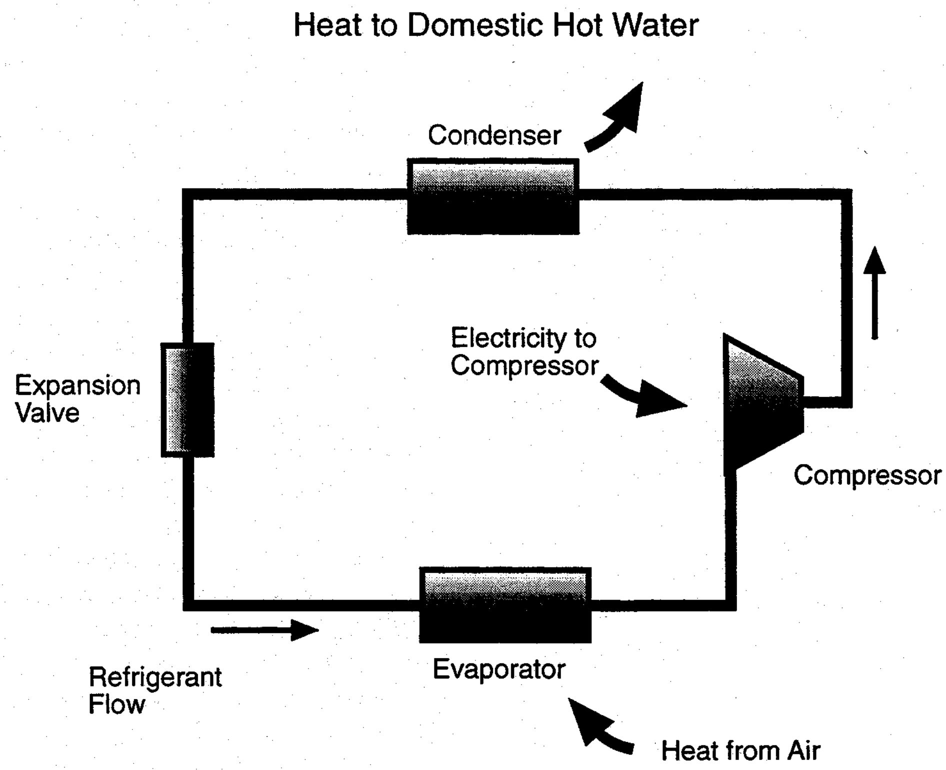


Fig 2. Schematic of Heat Pump Water Heater Showing Energy Transfer

the heat energy supplied to the water is typically between two and three times the amount of electrical energy required to operate the HPWH.

By contrast, electrical energy in a standard electric water heater is converted directly to heat in an electrically resistive element. Since the conversion efficiency from electrical energy to heat energy is 100%, and the element is completely immersed in the water, the amount of heat energy supplied to the water in a standard electric water heater is equal to the electrical energy supplied to the elements. By providing more hot water per unit of electricity consumed, the HPWH saves energy and money.

Residential HPWH units are wired with electrical resistance backup for heating water during periods when the HPWH will not operate satisfactorily. Backup electric resistance heat may prove necessary if the heat pump unit fails, or if the temperature of the heat source is too low for the HPWH to operate effectively. Some designs also allow the use of backup resistance heat if the hot-water load is significantly above the heat pump capacity.

Other Benefits

Energy-efficient water heating reduces water-heating energy costs. However, the HPWH technology offers benefits in addition to energy efficiency. Since HPWHs must extract heat from the air, they must continually exhaust cool air while operating. This cool air can be used to offset other space cooling loads, providing a "free" source of air conditioning and reducing space conditioning costs where demand for space cooling and water heating occur simultaneously. In addition, residential HPWH units are designed to draw significantly less power than electric resistance water heaters. As a result, they offer the potential to reduce electrical demand costs for areas where the site demand peak is coincidental with high residential hot-water usage.

Design Variations and Configurations

Four design variations for residential HPWHs exist; their use depends on whether the heat pump unit is integrated with the storage tank or is separate, and whether the cool exhaust air from the HPWH is exhausted into the residence or outside the residence. These variations are discussed below.

Storage tank variations. When the HPWH unit is separate from the storage tank, a pump is used to circulate water between the storage tank and the HPWH unit. The water is heated in the HPWH and then circulated back to the storage tank. A second option is to make the condenser an integral part of the hot-water tank. In this configuration, the HPWH and storage tank are manufactured and sold as a single unit.

Each design has its own advantages. If a flow loop is used to separate the HPWH from the storage tank, storage tanks or HPWH units can be replaced separately as they wear out. The separation also allows retrofit of existing electric resistance storage tanks to use a HPWH. Finally, there is more flexibility in fitting the HPWH into the available space.

A major advantage of the integral HPWH/storage tank design is that it eliminates the need for the water pump and flow loop. Eliminating the water pump reduces energy use as well as a potential maintenance problem. Eliminating the flow loop reduces an additional source of energy loss in the system as well the need for freeze protection for the flow loop. Obviously, the purchase price for this system includes the hot water tank, which is not the case with the separate HPWH/tank design.

Cool air exhaust configuration. Two configurations for the HPWH cold air exhaust are used for residential HPWHs; those which exhaust cool air into the living space (ambient-air HPWHs) and those which exhaust cool air outside the residence (exhaust-air HPWHs). The latter are also known as ventilating water heaters since they also provide mechanical ventilation for the residence. A third variety, based on water-to-water heat recovery, is used only in large apartment or commercial buildings and is not discussed in this Technology Alert.

Ambient-air HPWHs function by extracting heat from air taken from the residence and exhausting cool air back into the residence. Thus they cool room air while heating the water. Depending on space-conditioning requirements, this can be a benefit or a detriment to the energy use of the building. Figure 3a illustrates a typical ambient-air HPWH.

Exhaust-air HPWHs function by extracting waste heat from exhaust ventilation air using it to heat water. In Sweden, this design is used in about 75% of new homes (Caneta Research 1993b). This is not because the exhaust-air HPWHs are necessarily the most cost-effective water heater strategy, but because Swedish building codes effectively require both heat recovery and mechanical ventilation in new single-family residences and the exhaust-air HPWH does both. Figure 3b illustrates a typical exhaust-air heat recovery system.

The HPWH portion of exhaust-air HPWHs and ambient-air HPWHs are fundamentally the same. The difference is their effect on the building space temperature. Cool air provided by ambient-air HPWHs may be a benefit during the cooling season when it coincides with space cooling loads. During the heating season, however, the cool air produced by ambient-air HPWHs will increase the space heating load for the residence. In addition, if an ambient-air HPWH is installed in a location without adequate air circulation, it may cool the space temperature enough to seriously impact the performance of the water heater.

The impact of exhaust-air HPWHs on space-conditioning loads depends on the ventilation needs of the residence. If the mechanical ventilation provided by the HPWH does not exceed the ventilation requirements for the residence, there is no impact on space heating or cooling loads. If the mechanical ventilation provided is greater than the residence needs, however, space cooling and heating may be increased somewhat by the increased ventilation air. Exhaust-air HPWHs do not provide beneficial

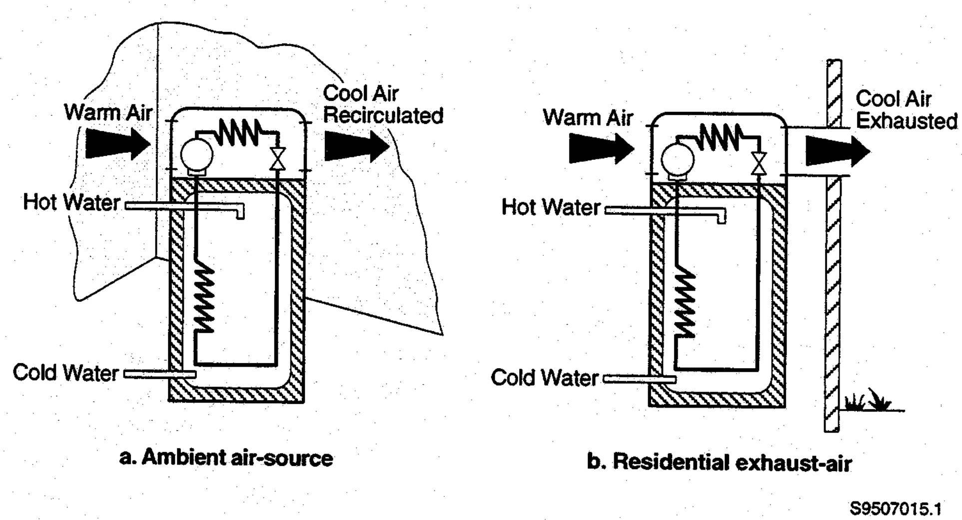


Fig 3. Typical Ambient-Air (a) and Exhaust-Air (b) Heat Pump Water Heating Systems

space cooling, since the air that is cooled by the unit is exhausted from the residence. Adjustable ventilation systems can be used to improve the usefulness of an exhaust-air HPWH. By adjusting dampers, the exhaust-air HPWH can be made to use warm outside air for the heat source and exhaust cool air into the residence, maximizing the water heating performance and now providing summer air conditioning and ventilation at the same time.

In general, exhaust-air HPWHs offer advantages in cold climates and in residences where mechanical ventilation is important (for example, unusually tight construction or areas with radon or other indoor air problems). Ambient-air HPWHs are a more economical choice for warm climates with high space cooling loads and with minimal to no space heating loads such as in the southern U.S. or Hawaii.

In theory it would be possible to have any HPWH ducted so it could operate as either an ambient-air or exhaust-air system; however, in the past, production models have been typically designed for one configuration or the other. Some newer designs are more flexible and ducting of air to and from these units is limited mostly by the creativeness of the installer and first cost considerations. The listing of HPWHs in the Suppliers section of this Alert shows their intended design.

It is not recommended that existing HPWH models be installed outside of a residence in a non-conditioned space (such as a shed or carport) at any site where the potential for freeze damage exists. This includes virtually all of the U.S. with the exception of Hawaii and other subtropical islands. In these locations the climate is warm enough that the cooling benefit from an indoor ambient air HPWH is often desired anyway.

Federal Sector Potential

The potential cost savings achievable by HPWH technology were estimated as a part of the technology assessment process of the New Technology Demonstration Program (NTDP).

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the *Commerce Business Daily* and trade journals, and through direct correspondence. Responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies). Note this solicitation process is ongoing and as additional suggestions are reviewed, they are evaluated and become potential NTDP participants.

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for the Federal Energy Management Program (FEMP), Construction Engineering Research Laboratory (CERL), and the Naval Facilities Engineering Service Center (NFESC) by Pacific Northwest Laboratory (PNL).

During the solicitation period in which HPWHs were suggested, 21 of 54 new energy-saving technologies were assessed using the modified FEDS. Thirty-three were eliminated in the qualitative pre-screening process for various reasons: not ready for production, not truly energy-saving, not applicable to a sufficient fraction of existing facilities, or not U.S. technology. Eighteen of the remaining 21 technologies, including residential HPWHs, were judged life-cycle cost-effective (at one or more Federal sites) in terms of installation cost, net present value, and energy savings. In addition, significant environmental savings from use of many of these technologies are likely through reductions in CO_2, NO_x and SO_2 emissions. Several of these technologies that have a demonstrated field performance have been slated for further study through *Federal Technology Alerts*.

Estimated Savings and Market Potential

Figure 4 shows four breakeven electricity cost curves for ambient air residential water heaters. Each curve shows the average electricity cost (including demand) necessary for a heat pump water heater to be life-cycle cost-effective as compared with an existing electric resistance water heater. The horizontal axis defines the climate location as a function of cooling degree days to a 65°F base temperature (CDD65). The upper two curves assume that space heating is provided by electric resistance heat and the lower two curves assume that space heat is provided by a heat pump. For electric energy costs higher than the chosen curve at a specific CDD65 value, the HPWH is likely to prove cost-effective.

The curves in Figure 4 were arrived at using an analysis technique described later in this Alert. To develop them, 32 different locations in the country were analyzed using this technique and the results curve-fitted to the CDD65 value for each site. Assumptions include a 6,000 Btu/hr ambient air HPWH retrofit with an installed cost of $985 and air-conditioning in the residence (nominal SEER 9.0). A daily average COP of 2.5 was assumed for this analysis. Differing first costs, family sizes, changes in air-conditioning use, and use of exhaust air HPWHs would generate different results.

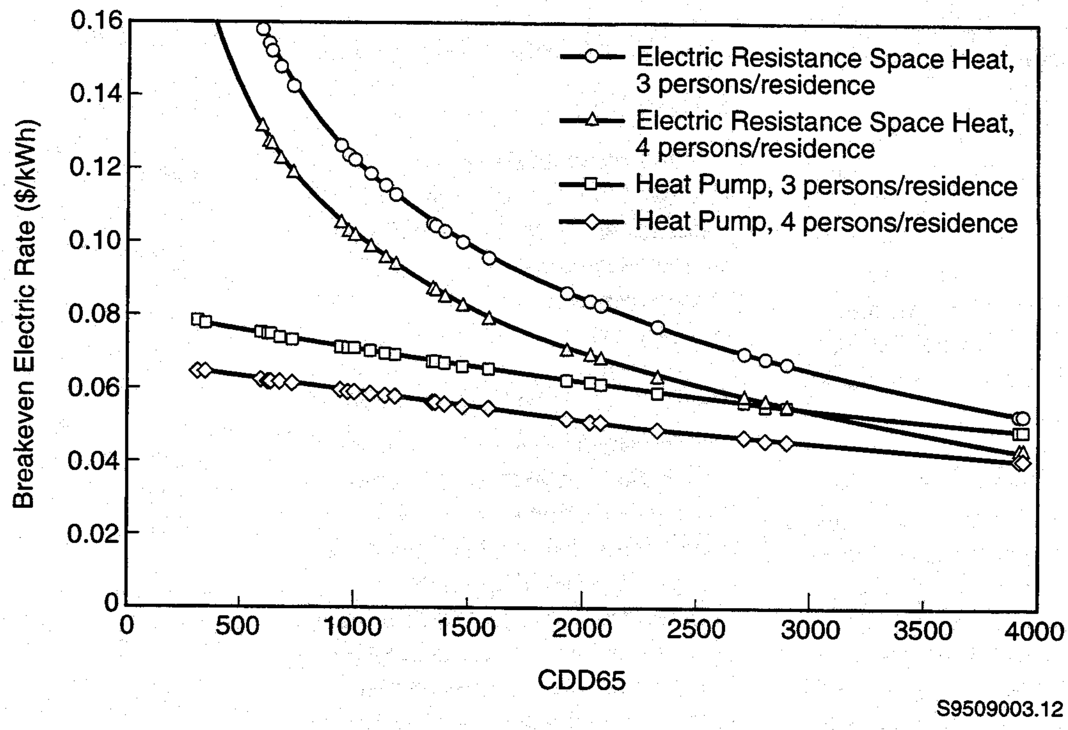


Fig. 4 Breakeven Electricity Cost Curves for an Ambient Air Heat Pump Water Heater Retrofit

Laboratory Perspective

Through laboratory testing and theoretical analysis, HPWH technology has been shown to be technically valid. The performance of HPWHs has also been conclusively demonstrated in the field. Economic attractiveness of the technology will depend largely on the site and the HPWH design used. Since the technology works by transferring heat, not by creating heat, its cost-effectiveness depends largely on the heat source and the point at which cold exhaust air is rejected. High initial cost and high maintenance requirements as compared with electric resistance or natural-gas water heaters limit the application of residential HPWHs in the Federal sector. In the niches where they are cost-effective, lack of awareness of the technology by some and past prejudices by others are remaining barriers to implementation. This FTA is intended to address these concerns by reporting on the collective experience of HPWH users and evaluators and by providing application guidance for Federal sector installations.

Application

This section addresses technical aspects of applying HPWH systems to residential buildings in the Federal sector. General guidelines are listed as to what things tend to make residential HPWH applications more cost-effective. Specific guidelines are listed as to where HPWHs should be avoided.

Where to Apply

The HPWH technology is most applicable under the following conditions:

- where electric resistance water heaters are presently used
- where electricity rates are high and where other alternatives (natural gas, propane, or oil) are expensive or not available
- in residences occupied by large (4 or more persons) families—where hot water use is high and where adequate space for a larger storage tank is available
- in warm climates where space cooling is important and space heating needs are low
- in mild/cool climates when heat pumps are used for space conditioning
- in mild/cool climates where there is a need for mechanical ventilation
- where electrical peak loads coincide with residential water heating peak loads, typically around 7 a.m. and 6 to 7 p.m.
- in mild/cool climates where the water heater can extract heat from a large, unconditioned basement or crawl space

- where ease of ductablitiy of the exhaust and inlet air streams can minimize negative impacts on household space conditioning energy use

What to Avoid

- Use of HPWHs should probably be avoided wherever hot water consumption is low (such as in small residential units or those with high rates of vacancy).

- Ambient air HPWHs should be avoided in mild or cool climates where electric resistance space heat is used.

- HPWHs require regular maintenance during the year. Where such regular maintenance cannot or will not be provided, HPWHs are not recommended.

- HPWHs should not be installed in unventilated closets or small rooms inside a residence unless a ducted air supply can be provided.

- HPWHs are not recommended for installation in outside or unconditioned spaces where the potential for freezing conditions exists.

Installation and Service Issues

Actual maintenance costs for newer HPWHs are largely unknown, and estimates vary from "low" (like refrigerators) to very high. Past experience at military sites that use HPWHs suggests that 2 hours per year should be expected for preventative maintenance activities. Major component failures (such as a compressor or pump impeller) during the expected lifetime of the unit have been common in the past.

Experience has demonstrated that effective HPWH operation and long life are highly dependent on proper installation. Installation and maintenance of HPWHs should only be implemented by those familiar with the technology. This is particularly important at large Federal installations where mistakes made during installation may be repeated over hundreds of units installed. Third-party commissioning of the intended installations and a representative sample of the HPWHs installed by someone familiar with the technology may be a useful approach to avoiding future problems.

Because the installation and maintenance of HPWHs require knowledge from what have traditionally been different disciplines (plumbing and refrigeration/HVAC) and because of the small market for these systems, finding someone familiar with the technology may be difficult. It may also require organization of what have been traditionally different job shops on a Federal site to maintain units once installed. For example, aside from simply understanding the technology, water heater service technicians must have the knowledge, skill, and equipment to comply with government regulations concerning refrigerant recycling and release as would be expected of anyone servicing refrigeration or air-conditioning equipment.

A number of issues should be addressed by anyone planning to install HPWH units:

- what type of HPWH is most appropriate for their climate/ application, ambient-air or exhaust-air

- how to avoid house locations where freezing temperatures might exist

- how to optimally use available cooling

- is the existing tank size adequate for retrofit applications

- is there adequate space to accommodate a possibly larger storage tank

- can the HPWH be placed in a well-ventilated location

- will it be easier to move the water heater location than duct air to the HPWH

- will cool exhaust air cause a single room to feel drafty

- is there a location for condensate drain and will a condensate pump be necessary to remove water

- who will be responsible for regular maintenance and repairs to HPWH systems

Installation practices depend on the HPWH design. Several specific issues are as follows:

Ambient-air Designs. In ambient-air designs that discharge cool air into the residence, the area from which the HPWH will draw air must be room size (1000 ft^3 or larger) or adequately vented to other parts of the house to prevent over-cooling of the space. Since the heat for hot water is drawn from the house air, ambient-air HPWHs are considerably more cost-effective in moderate climates when the additional space heat required during the heating season is made up with a heat pump. Where electric resistance space heat is used, there will be no advantage of an HPWH over an electric resistance water heater during the heating season. For warm climates with very low heating requirements this is not a significant disadvantage (Hawaii, South Florida).

Because HPWHs produce cool air that is then exhausted via a fan, they have a tendency to make the room in which they exhaust air feel colder than it actually is. Diffusion of the exhaust air through as large of space as possible is valuable in keeping occupants comfortable.

Exhaust-air Designs. It is important not to use exhaust-air HPWH units in residences that have open-flame devices (gas stoves, fireplaces, etc.) unless there is a separate makeup air supply for the space containing those devices. Otherwise the HPWH may interfere with the normal venting of fumes from these devices. It is important to have adequate space for the installation of ductwork, usually above the HPWH. Ventilation levels must be set with exhaust-air designs, as well as timers, to provide ventilation when hot water is not being produced if it is necessary for the residence.

It is valuable to consider ducting of the air source and air exhaust from some of the newer, ostensibly ambient air, HPWH units. For example, ducting of source air from a ventilated attic and exhausting it outdoors may be a good design in a mild climate to recover heat lost through the ceiling of the house in winter. In summer, warm attic air may provide a good heat source for the HPWH, although the design would have to make sure that the inlet air is always within the operating conditions of the specified HPWH unit. For each area of the country and for each housing design, there will be different configurations that maximize HPWH efficiency while minimizing any negative impact on space conditioning loads. For anyone interested in large-scale residential HPWH implementation it is advised that they consult with HPWH manufacturers and local utilities with experience with the technology to devise the most cost-effective installation for their location and building designs.

Both Designs. It is important that either system installed be monitored for the first few days by the occupant, particularly for buildup of ice on the evaporator coils which may be indicative of a number of problems such as low refrigerant charge, refrigerant leak, compressor problems, or plugged expansion device. These problems will also reduce the HPWH water heating capacity and efficiency, but because electric resistance elements may compensate and because the occupant may be unfamiliar with the HPWH, poor performance of the HPWH may go unnoticed, and much of the efficiency advantage of the HPWH system could be lost.

Maintenance

Regular maintenance is important for high efficiency and long life of HPWHs. Regular maintenance activities are simple. Typical regular maintenance activities and recommended frequencies are shown in Table 1 as reported for one manufacturer's product line.

Repair of any water leaks at the HPWH is important to prevent corrosion of any of the HPWH components. In areas of hard, alkaline water, scale buildup may occur on the water side of the condenser coil. Cleaning this scale can be simple or complicated, depending on the HPWH design.

Parts that may require repair/ replacement over the life of the HPWH include compressors, water pumps, fan motors, and expansion devices. Warranties on residential HPWHs typically only cover parts for 1 to 4 years and labor for only a short time after purchase.

Table 1. Regular Maintenance Activities for HPWHs

Maintenance Activity	Frequency
Clean/replace air filters	every 2-3 months depending on buildup
Check condensate drain	every 6 months
Oil fan motors	every 6 months
Clean Evaporator Coils	as needed

Costs

First cost for HPWHs varies widely and list prices for basic add-on HPWH units start at about $600. Quantitity purchases may reduce this figure somewhat, although there may also be additional costs for components for connecting to the existing water heater or mounting the HPWH in the space.

Installation costs for HPWHs reflect the complexity and lack of experience with the technology. Installation costs for ambient-air HPWHs during utility testing and rebate programs have varied from $300/unit to $700/unit (Little 1994). Costs for exhaust-air HPWHs should be expected to lie at the upper end of that range and costs for ambient-air units at the lower end. Installation cost will vary with quantity of units installed, specificity of installation design, and installer familiarity with the technology.

Anyone contemplating installation of HPWH units should check with local suppliers and/or installers to determine availability of service, equipment warranties, and installation costs. The market for residential HPWHs is still very small and it may be worthwhile to consult manufacturer's directly to find local installers and distributors of the technology.

Unit cost for HPWHs technology may decrease substantially if manufacturers increase production of HPWHs. Because components and complexity are similar to residential room air-conditioners, large HPWH markets could result in HPWH cost approaching that of conventional room air-conditioners (Little 1994) and make HPWHs considerably more cost-effective in the future.

Rebates

The local utility company should be contacted for information about relevant programs and incentives that encourage HPWH use. A 1992 survey of utility demand-side management programs (EPRI 1993) identified 15 out of 175 utilities which offered incentives for the adoption of residential HPWHs. Several other utilities are presently running test programs to determine the feasibility of including HPWHs in their own demand-side management programs. Although in general, most utilities are moving away from offering rebates for the adoption of residential sector energy-saving technologies, the impact of widespread adoption of HPWH technology at a large Federal site may make a utility interested in offering a special, negotiable rebate to the site.

Available Products

Table 2 identifies the available residential HPWH products in the U.S., based on requests from industry for such information. Other residential HPWH models may exist, and there is no attempt to preclude their inclusion through addenda or in future FTAs.

Additional Considerations

Anyone contemplating the use of HPWH technology in the Federal sector should be aware of the following considerations.

Maintenance and Repair. Maintenance and repair needs for many residential HPWH models have tarnished their reputation severely. The technology is relatively complex compared with electric resistance and fossil-fuel water heaters, so a higher level of necessary maintenance should be expected. At Federal sites where HPWHs have been used successfully, regular maintenance activities and system checks have been important in keeping existing HPWHs in good operation. At these sites, the brunt of the regular maintenance activities has been borne by the housing maintenance department, since the tenants have no vested interest in maintaining the HPWHs. The cost of this regular maintenance must be figured into the HPWH economics. Required maintenance must be done. Without adequate funding and support for at least some regular maintenance, HPWHs will not prove cost-effective.

Heating Capacity. Hot water heating capacity is typically between 40% to 100% of electric resistance water heater capacity and 30% to 50% of typical gas water heaters. Consequently, HPWH manufacturers recommend the use of larger storage tanks than other water heater types serving the same residence hot-water

Table 2. Available Residential Water Heater Products

Company	Model	Water Heating Capacity (Btu/hr)	Cooling Capacity (Btu/hr)	Water Heating COP, nominal	Energy Factor Rating[a]	First Hour Rating (Gallons)	Electrical Power Input (kW)	Tank Size (Gal)	Price
Ambient Air HPWHs									
E-Tech/Crispaire									
	WH-6A[b]	6,000	4,000	N.A.	2.61	16.9	0.5	NA	$600
	WH-6B	6,000	4,000	N.A.	2.61	16.9	0.5	NA	$600
	B108K2	12,000	7,100	3.2[b]	1.5	58	1.0	NA	$900
	R106K2	12,000	7,100	3.2[b]	1.9	58	1.0	NA	$900
DEC-Therma-Stor									
	HP-80	10,600	7,500	2.5	2.5	62	0.8	80	$1,425
	TS-HP-80-HRA	10,600	7,700	2.5	2.52	62	3.4	82	
	TS-HP-120-18-30	10,600	7,700	3.7[c]	2.5	99	6.8	120	$1,748
	HP-120-27	15,300	10,200	3.0[c]	NA	NA	1.5	120	$2,664 to $2,859
Exhaust Air HPWHs									
DEC Therma-Vent									
	HP-VAC-80	8,300	7,000	2.1	2.1	70	1.2	80	$2,082
	HP-VAC-120	8,300	7,000	2.2	2.2	103	1.1	120	$2,229
	VHP-80	7,100	6,000[d]	2.5	2.65	64	3.3	80	$1,521

(a) Energy Factor Ratings from Product literature or from California Energy Commission Database on Residential Water Heater Performance.
(b) Temporarily removed from the market as of May 1995.
(c) COP calculated based on GAMA (Gas Appliance Manufacturers Association) energy factor test procedure.
(d) If exhaust air is ducted back into the residence.

load. Increasing the amount of hot water stored allows the HPWH/ storage tank system to meet the same peak hot water load even though the HPWH has a lower water heating capacity. Larger tank sizes are more expensive and take up more space in a residence. Several existing manufacturers' designs allow an installer to configure the HPWHs to compensate for low output capacity by engaging the hot-water tank's upper electric resistance heater element during periods of high demand. This increases effective peak output capacity and allows smaller tank sizes at the expense of increased peak electrical demand and reduced energy efficiency.

Noise. HPWHs have a reputation for being noisy. A U.S. Army Corps of Engineers study at Hickam Air Force Base (Towill 1988a) recorded average noise levels from 67 dBA at a distance of one foot from the heater (comparable to that of a window air conditioner), to 52 dBA ten feet away, and to 45 dBA in the residence bedrooms (comparable to a quiet radio playing). The report indicated general tolerance by occupants to the noise. Housing and Maintenance personnel at Federal facilities who use HPWHs suggest that the additional noise is a minor irritation to the occupants but has not been a strong disincentive to the use of HPWHs at these sites.

Space Requirements. An advantage of electric resistance heaters is that they can easily be tucked into a small closet-like space in a residence. Not only do HPWHs often require larger tanks, because some designs exhaust cool air to the space surrounding the HPWH, they must be located in sufficiently large and well-ventilated rooms to ensure that they do not overcool the space. A spokesperson for the National Association of Homebuilders testified at a DOE hearing on a proposed HPWH standard that the extra floor space required to accommodate an HPWH could add up to $750 to the cost of a new home based on a conservative estimate of $50/square foot (Little 1994). The actual cost of any lost living space will depend on each particular installation, however.

Refrigerants. Use of refrigerants is now a regulatory issue. All existing residential U.S. HPWH models use R-22, a hydroclorofluorocarbon (HCFC). As an HCFC, R-22 does not have the significant environmental impact attributed to clorofluorocarbon (CFC) refrigerants such as R-12. Nevertheless, some level of environmental impact is expected, and R-22 is scheduled to be phased out of production by the year 2020 (Salas 1992). The largest impact of these regulations has been in the cost of maintenance activities. Present law requires that R-22 be recovered and recycled, requiring that installers and service technicians have the skills and equipment to recover refrigerant during maintenance activities.

Availability. Only a few models of residential HPWHs are currently being manufactured or sold in the United States. The industry has focused instead on commercial units where the economics are more tenable. The market for residential HPWHs has been steadily declining since the 1980s. Currently there are only two U.S. manufacturers of residential HPWHs, and the present market for residential HPWHs is about 2,000 units/yr. This has resulted in only a few available models at relatively high costs. A listing of the residential HPWH products available in the U.S. is provided in the Suppliers section of this Alert. In addition, the infrastructure for sales, installation, and maintenance of HPWHs, as well as supply of parts, is in its infancy, increasing time to purchase, install, and repair HPWHs compared with more conventional water heaters.

Interaction with Space Conditioning. The potential effect on space conditioning energy use means that considerable care must go into determining whether HPWHs are a cost-effective alternative to electric water heat. More engineering analysis must precede the decision to use HPWHs; moreover, uncertainty in the final economic analysis (particularly with regard to unforeseen repair or maintenance requirements) means that a Federal facility will assume more risk than with better known technologies such as gas or electric resistance water heaters.

Technology Performance

In the past 15 years, it is estimated that between 40,000 and 60,000 residential HPWHs have likely been sold in the U.S. An additional 200,000 to 300,000 residential HPWHs have been installed in Europe (Caneta Research 1993a). Laboratory and field measurements of the performance of residential HPWHs are documented in this section, as are field maintenance experiences in the U.S.

Performance Indices

Two terminologies are used to describe the performance of HPWHs, the heating coefficient of performance (COP) and the Energy Factor (EF). Both terms are commonly used for residential HPWHs; however, the EF rating is also used for other residential water heaters and is based on a specific test procedure, so it offers an easier comparison of performance with other water heater types.

Energy Factor. The EF rating is used in the U.S. as an estimate of the seasonal efficiency of residential water heaters. The EF is the ratio of heat output to energy input for a water heater as measured during a specific 24-hour laboratory test procedure. The latest version of this test was adopted by the DOE in 1991. In this test, 64.3 gallons of hot water at 135°F are removed from the hot-water tank in six equal draws (10.7 gallons per draw) occurring at the beginning of each of the first six hours of the testing period. No other draws are made for the rest of the 24-hour test period. This EF test takes into account recovery efficiency and standby losses from the water heater and storage tank. In theory, an HPWH with an EF of 2.0 will, on a daily average, provide hot-water energy to the residence equal to twice the electrical energy input to the HPWH. In practice, the ratio of hot water to electrical energy for an actual installation may vary significantly from the rated EF because of other parameters affecting the HPWH. Parameters held fixed in the test are an ambient air temperature of 67.5°F and an inlet water temperature of 58°F. Additionally, relative humidity for HPWHs is required to be between 49% and 51% during the test. Variations in any of these values from the nominal test conditions are accounted for in calculating the EF. The testing procedure and calculations used to determine the EF are the same for all residential water heaters regardless of energy source. EF ratings for the available U.S. residential HPWH models are seen in the Suppliers section of this Alert.

Coefficient of Performance. The heating COP is the ratio of heat energy output from the HPWH to the electrical energy input to the unit when both are measured in consistent units: Heating COP = Heating Energy Output / Electrical Energy Input.

A heating COP of 2.0 means that the heat energy output of the water heater is twice the electrical energy input. Since there is no standard rating condition of heating COP for HPWHs, a manufacturer-reported COP must be understood in the context of how the unit was tested. For example, the EF rating can be considered a COP rating for one particular, 24-hour, test procedure.

Variation in Test Procedures

The original EF test procedure was developed by GAMA (Gas Appliance Manufacturers Association) in the early 1980s and calculated the EF from separate recovery efficiency and standby loss tests, as is common in commercial water-heating equipment. COPs based upon the recovery efficiency determined in this procedure are still reported for some residential HPWHs, although the standard is no longer official.

In the GAMA test procedure, the HPWH was required to heat water either in the tank supplied with the water heater or in a separate storage tank. To determine the recovery efficiency for the system (the COP rating), the tank was filled with water at an initial temperature of 55°F, and the HPWH was used to heat the water in the tank until the average water temperature was 135°F. The room temperature was held at 75°F and the room humidity at 50% during the test. The COP rating for the HPWH was the recovery efficiency, which was calculated by dividing the total heat energy supplied to the water during the test (as calculated by the tank volume and temperature rise) by the electrical energy input to the HPWH. The test simulates completely emptying the storage tank of hot water and then letting it heat up with no load. In this test, the average water temperature during the time the heat pump is operating is 95°F, or only 20°F above the room temperature.

The performance of all heat pumps depends on a number of conditions, the most important being the hot-water temperature (which controls the condensing temperature of the heat pump) and the inlet air temperature (which controls the evaporator temperature of the heat pump). The inlet air humidity also affects performance. In general, the greater the temperature difference between the water temperature and the ambient-air temperature, the lower the efficiency of the HPWH. Since the GAMA test simulates a single large hot water draw versus the six small draws used for the DOE EF test, the average tank temperature and consequently the condenser temperature are lower for the GAMA test. The ambient room temperature (heat source temperature) is also slightly higher in the GAMA test, and the combination makes the HPWH operate more efficiently. On average, EF ratings calculated using the GAMA test procedure are 42% higher than the corresponding DOE EF (Abrahms 1992). Because they do not necessarily include standby losses, COP ratings from the GAMA test procedure can be up to 113% higher than the corresponding DOE EF rating for the same HPWH.

Because COP ratings are not standardized in the industry, do not necessarily include standby losses, and are not typically used for other types of water heaters, using manufacturers' COP for comparing expected annual performance of residential HPWHs with other water heaters (heat pump or otherwise) is difficult. The EF rating is more appropriate for this purpose.

COP ratings are useful for examining how the performance of an HPWH changes with operating conditions. Figure 5 illustrates how the COP of one manufacturer's residential HPWH varies with final tank temperature. Note, in this instance the manufacturer-calculated COP was determined by heating a tank of water from 70°F to the final tank temperature seen on the X-axis. As the leaving water temperature increases from 100°F to 130°F, the COP is reduced by 15%.

Performance of HPWHs improves with more humid inlet air conditions. As the air becomes more humid, there is more latent heat that can be extracted from the air for a given evaporator temperature. This

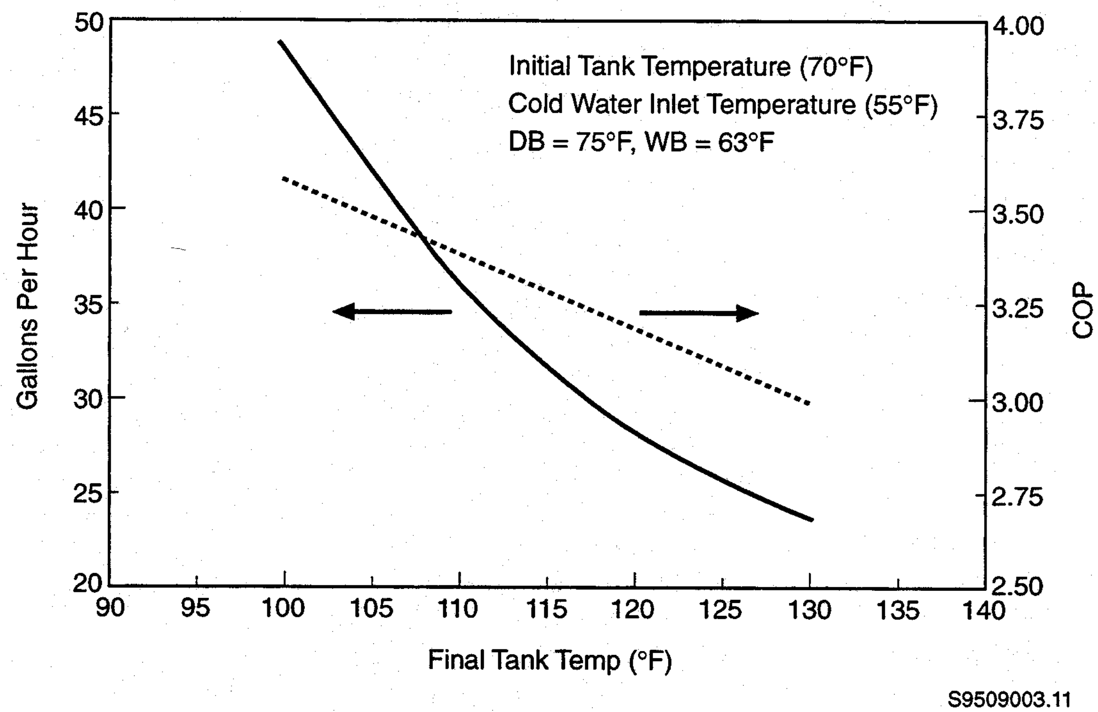


Fig. 5. Performance Chart for Typical Residential Heat Pump Water Heater

increases both the efficiency and capacity of the HPWH system. According to one HPWH manufacturer, they have seen as much as a 20% improvement in performance when a system is operated at a relative humidity of 70% as when operated at a relative humidity of 30%. This can be important if the residence is located in a warm, humid climate and is not air-conditioned.

A criticism of the EF test is that the size and frequency of hot-water draws used are not typical of actual residential water use. In many households, hot-water demand is often very high in the morning for about an hour, moderately high in the evening hours, and very low during much of the day. Especially in smaller units, high morning draws can cause the electric resistance backup elements to operate, reducing the efficiency of the HPWH below what may be reported in the EF test. A counter argument is that once the average temperature of the water tank has been reduced substantially, the average condenser temperature is lower while the storage water is being heated, and the HPWH will perform more efficiently. The variation of performance under different use scenarios is substantially less with other water-heating technologies. Several water heater manufacturers and other organizations (notably the GAMA and the Electric Power Research Institute [EPRI]) are working in conjunction with the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) to develop improved test procedures for HPWHs.

Heating Capacity

The water-heating capacity for residential HPWH units is typically rated in Btu per hour of hot-water energy output. Often, the capacity is also shown as recovery, or number of gallons of hot water that can be produced in a certain time period (typically one hour) at a specific hot-water outlet and inlet temperature. Heating capacity, like COP, is dependent on test conditions, and varies with ambient-air and outlet-water temperatures. In general, larger temperature differences between the ambient air and the hot-water tank result in lower water-heating capacity. This relationship is shown in Figure 5 for a specified unit (nominal capacity 12,000 Btu/hr) based on the same test procedure as was used to calculate COP. As the leaving water temperature increased from 100°F to 130°F, the number of gallons supplied at the requested temperature decreased by over 50%. The actual capacity of the unit (expressed in Btu/hr of hot water output) decreased by 25%.

The water-heating capacities of residential HPWH units are lower than heating capacities of typical electric resistance and gas-fired water heaters. Nominal capacities for available residential HPWH units vary between 6,000 and 15,300 Btu/hr, and as illustrated, can be significantly reduced by environmental factors. Typical water-heating output for electric resistance water heaters (with the standard 4,500 W electric element) is just over 15,000 Btu/hr once shell losses are taken into account. Typical residential gas water heaters have input ratings of 28,000 to 55,000 Btu/hr, corresponding to water-heating capacities between 21,000 to 44,000 Btu/hr once typical combustion efficiencies and shell losses are taken into account.

Existing U.S. manufacturers of residential HPWHs offer models that make use of electric resistance heating elements to boost the capacity of their water heaters and help ensure adequate hot-water supply in some of their product lines. This is done by using two thermostats on the hot-water tanks. The lower thermostat is used to control the HPWH only, the upper thermostat controls an electric resistance heating element. During periods of water use, cold supply water enters the bottom of the tank and triggers the lower thermostat, which turns on the heat pump. If hot water from the tank is used at a faster rate than it can be supplied by the HPWH, the level of cold water in the tank gradually rises. If the water use continues, the cold water will eventually trigger the upper tank thermostat and turn on the electric resistance element. This process increases the capacity of the water-heating system; however, it reduces the efficiency of the system as a whole. It should be noted that these electric resistance backups are effectively disabled during EF testing.

A first hour rating is sometimes used for HPWHs. The first hour rating has its basis in the first hour rating section of the DOE test procedure (10 CFR 430), and is a calculation of the amount of hot water that could theoretically be removed from the water heater before the temperature of water leaving the tank drops to 110°F (25°F below the initial temperature). First hour rating is largely a function of storage tank size. For typical residential water usage patterns, first hour ratings are often a better indicator of hot-water availability than heating capacity or recovery, since for electric water heaters (heat pump or electric resistance) the energy in the "available" hot water stored in the tank (typically considered to be 70% to 80% of the tank volume) is equal to or greater than the energy provided by the heat pump or electric element in a one-hour period. Note, in the DOE Energy Factor test, the tank size used with add-on HPWHs (those sold without an integral tank) is 47 gallons. If a larger, manufacturer-recommended tank size is used, the available hot water will be greater than indicated by the first hour rating.

Energy Factors, Nominal COPs, nominal heating capacities, and first hour ratings for U.S.-manufactured HPWHs are shown under "Available Products."

Number of Field Installations

The number of residential HPWHs currently in operation in the U.S. is unknown, but probably approaches 40,000. The market is so small that the Air Conditioning and Refrigeration Institute (ARI) does not track sales. According to the Hawaiian Electric Company, a large fraction of these HPWHs are in Hawaii, where approximately 25,000 residential HPWHs have been installed since 1979. Approximately 11,000 of these units were installed at Federal military sites, with at least 5,000 of these units still in operation. In addition, approximately 35,000 more private residences receive hot water from commercial HPWHs installed in multifamily housing units.

Installation of large, commercial HPWHs to supply hot water to central water-heating systems for large, multi-unit housing complexes will prove to be considerably more cost effective than use of small residential units is such housing designs.

Field Experience

Military personnel at various bases where HPWHs have been installed consistently report that upon installation, an initial drop in area-wide residential electric consumption was seen, although the exact amount that could be attributed to HPWH was unknown, since on most bases residences are not individually metered. A test of units installed at Hickam Air Force Base and Aliamanu Military Reservation in Hawaii (Towill 1988a and Towill 1988b) showed an average operating COP of 2.66 during testing (94% of the manufacturer's rating for the actual operating conditions).

A Bonneville Power Administration study (BPA 1994) examined the performance of exhaust-air heat pump water heaters in 31 homes located in the Pacific Northwest. In phase 1 of this study, performance was monitored over 13 months, from 1992 through 1993. Phase 2 of this study (BPA 1995) continued monitoring of 10 of these units from September 1994 to April 1995. The metered outputs included the electric input energy, and the hot-water temperature, hot-water flow, and energy output. The daily average COP was measured to be 2.0, not including any resistance heat backup, for both testing phases. The rated EF for the units was 2.5. Several units performed at or above this level, several were slightly below, and two units were well below it. One unit in particular had been placed in an unheated basement, and the cold exhaust air was allowed to short circuit to the supply air. The resulting COP for this unit was 1.3 over the 13-month test.

Electric resistance backup energy averaged 2% of the total HPWH usage in phase 1 of the Bonneville study and 4% in phase 2 of the study, or 1 to 2% of the hot water energy requirements of the household. All but one of the units analyzed in phase 1 and all the units in phase 2 used an 80-gallon storage tank (the single exception in phase 1 used a 120-gallon storage tank).

Field studies on residential HPWHs in the 1980s indicate wide variations in metered performance, with daily average measured COPs between 1.2 and 3.5 being reported in the HPWH literature (Caneta Research 1993a). In general, metered performance for the various HPWHs examined in these studies indicates that a daily average COP for a residential HPWH is typically between 1.5 to 2.5.

Reported in almost all studies is a marked improvement of daily average COP with higher levels of hot-water usage. This occurs for two reasons. Higher usage means that makeup of storage losses is a smaller fraction of the energy use; more importantly, higher usage means that the average water temperature is lower in the storage tank and thus the condenser temperature is lower, improving heat pump performance. The effect is clearly seen in the BPA study above, where the daily COP varied between 1.5 and 2.5 as the hot-water usage varied between 500 and 3500 gallons/month. Note that because of this effect, performance of heat pump water heaters can vary not only by volume of hot-water use, but also by load profile. Many small hot-water draws during the day can result in an average condenser temperature during HPWH operation that is fairly high, whereas if the same amount of hot water energy is required by the residence with a few large hot-water draws, the large draws will result in a lower average water temperature in the tank and a higher COP during the recovery period.

A difficulty with most of the studies is that the impact on residential space conditioning energy use has not been adequately analyzed. Recent studies have tended to focus on the performance of the HPWH alone.

Installation

Much of the historically poor service record for this technology can be attributed to improper installation. Many of the early installations of HPWHs at military sites in the southern U.S. were in unheated storage areas adjacent to houses. The piping in many of these units froze and broke during short periods of freezing weather, reducing the life of the units to less than five years. In another example, an HPWH design which allowed the use of only one electric resistance element for backup heat was wired to replacement tanks with two elements. The electrical wiring in the HPWHs could not take the higher load of both elements operating simultaneously, and as a result, the wiring in many of the HPWH units burned out. Incidents like these point to the need to have HPWHs installed by someone familiar with the technology and with potential problems.

Maintenance Requirements

Maintenance data from HPWH studies are sparse. In phase 1 of the BPA study, 31 exhaust-air HPWHs monitored for 13 months required, in total, only one repair visit to fix a broken electrical relay. However, several visits were made to adjust refrigerant charge soon after initial installation. In the continuation of this study (BPA 1995), 10 units were monitored for an additional year. One unit developed a refrigerant leak and had to be recharged during the year. A second had to have a motor capacitor replaced. No other unscheduled maintenance requirements were documented, although in one case the owner shut down his system to help with defrosting. If 2-man-hours per maintenance visit is assumed (to arrive at site, diagnose problem, and repair), this averages 0.1 man-hours/unit the first year and 0.4 man-hours/unit the second year for repair visits. In this study, preventative maintenance needs (primarily filter changes and cleaning of condensate drains) were assumed to be the responsibility of the homeowner. Examination of the HPWH air filters during phase 2 indicated that most filters were dirty and required cleaning. It was reported that in some sites, the filters had not been cleaned since installation 2 years previously.

Discussions with maintenance personnel at military bases in Hawaii suggest considerably higher maintenance for older units. At one air force base, repair activities for 10-year-old add-on HPWHs account for approximately 1.7 man-hours/unit/yr, primarily for rebuilding and replacing compressors and pumps. According to maintenance personnel, the cost to replace the compressor in each of these heat pumps was $253/unit, including labor. These costs are above and beyond the cost of tank replacement, which occurs at the same frequency as with electric resistance water heaters. Note, personnel at this base indicated that as there were only a few major components, it was more cost-effective to repair the existing units then to purchase new units.

Scheduled regular maintenance activities are suggested for all HPWHs. Air filters and condensate drains need regular cleaning, and an annual check on the refrigerant charge and compressor amperage draw is common. At most Federal installations, water heater maintenance is part of the housing maintenance contract. Three Hawaiian military bases contacted about regular maintenance of HPWH units reported that they schedule between 1.3 and 2 hours per HPWH annually for routine maintenance.

Energy Savings

The first phase of the BPA study reported energy savings averaging 2,200 kWh per year for the exhaust-air HPWH units. The average installed cost was $1,800, and the simple payback period was 16.4 years (calculated for $.05/kWh rates). The 10 units monitored in the second phase of the study showed essentially the same level of savings. The average hot water energy use in this study was approximately 13.5 million Btu/yr, or 90% of the typical hot-water usage of 15 million Btu/yr estimated by the DOE (10 CFR 430).

Federal Standards Related to Energy Efficiency in Residential HPWHs

The following standards are relevant for residential HPWHs as used in the Federal sector

10 CFR 430: The Code of Federal Regulations (CFR) is a codification and explanation of the rules published in the Federal Register by the Federal government for Federal organizations. Volume 10 of the Code of Federal Regulations (parts 400 to 499) refers to energy use, and section 430 in particular refers to the Energy Conservation Program for Consumer Products.

NAECA: The National Appliance Energy Conservation Act of 1987 and the National Appliance Energy Conservation Amendments of 1988 (P.L. 100-357) provide energy conservation standards for consumer products including residential water heaters and authorizes the Secretary of Energy to prescribe amended or new energy standards for each product category covered.

Energy Savings

Estimating energy savings from proposed HPWH installations can be accomplished using the methodology outlined below.

Step 1) Gather Necessary Background Data. Appendix B contains a worksheet showing the necessary background data to be gathered for evaluating a potential HPWH application. It also contains a section dealing with all necessary calculations for determining the energy use of the electric resistance and HPWH technologies.

Step 2) Estimate Residence Hot-water Load. This is one of the most difficult values to determine with certainty; every household is unique. A good starting point, however, is to estimate the hot-water load from the average number of individuals served by a water heater. DOE estimates 64.3 gallons/day of 135°F water as a typical load for a four-person household (10 CFR 430).[a]

The number of individuals who would typically be served by a water heater can be estimated from site data (Note, default = 3.0). Since much of the hot-water usage is for fixed-water consumption, a good assumption is that the first person in the residence uses 32.2 gallons/day and that each additional person uses 10.7 gallons (Taylor 1991).

The cold water inlet temperature is important for determining the energy needed to heat water. Typical shallow-ground water temperatures for 75 major U.S. cities are shown in Appendix D.

The average daily hot-water energy supplied to the residence can be calculated as the product of the specific heat for water times the hot water used times the increase in temperature from the cold water supply to 135°F, or

HW Energy Load (Btu/day) = 8.28 Btu/gal x Hot-water Load (gal/day) x (135 °F - CW supply temperature)

Step 3) Estimate Water Heater Lifetime and Costs. Retail cost data for existing HPWHs are included in Table 2; however, unit costs may vary with quantity purchased. Installation cost may very significantly, depending on technology, installers' experience with the technology, and the number of installations. Several supplier estimates should be obtained. Note that HPWH units designed to be retrofit to existing electric resistance hot-water tanks will likely require replacement of the electric resistance tank during the life of the HPWH. Typical life for an electric resistance tank is approximately 10 years. Lacking better information, assume that the tank is halfway through its life and expect that an additional tank will be needed 5 years after HPWH installation. Note that there should be no expected change in tank life for an add-on type of HPWH.

As discussed above, maintenance costs with HPWHs may be significantly higher than with electric resistance water heaters. At least 2.0 hours/year of preventative maintenance should be estimated for the life of the HPWH. There may be unforeseen repairs as the unit gets older and individual components fail. Manufacturers' expected service life for HPWH is typically around 12 years. Past field experiences with the technology suggests that this may be a high estimate. Here it is suggested that the expected 12-year service life be reduced somewhat to account for possible premature failure. When a malfunction occurs, the HPWH can be switched to use electric resistance elements and essentially becomes an electric resistance water heater; discussions with some sites with HPWH experience indicate that this

(a) Estimates of typical hot water requirements from other sources vary 50% above and below this figure, and likely reflect real life variance in hot water consumption. 64.3 gallons for four persons is a reasonable estimate, and for many Federal sites, where the occupants do not pay for the hot water energy, may be conservative.

is almost as common as repairing the unit. Assuming a 10% failure rate beyond the 5th year, and failure of the remaining units at the 12th year, one calculates an expected life of 10 years for any single unit.

Step 4) Estimate System Performance. A good starting point for estimating energy use is to use EF ratings. Although actual performance will vary with hot water load and surrounding room temperatures, EF ratings provide a single performance parameter for comparing water-heating technologies that includes real-world parameters such as storage losses. The Federal government requires that all electric resistance water heaters purchased after 1990 have an EF of at least 0.88. The prior EF requirement (for water heaters purchased between 1982 and 1990) was 0.82; however, existing water heaters of this vintage will be replaced with more-efficient systems in the near future. An EF of at least 0.88 should be used for existing water heaters installed after 1990, and an EF of no less than 0.85 should be assumed for electric resistance water heaters installed before 1990, since they would need to be replaced with the more efficient units over the life-cycle analysis.

All water heaters are in peak condition when rated according to the DOE test procedures. However, performance of HPWHs is more susceptible to differences in operating conditions than performance of gas or electric resistance water heaters. In this procedure, it is suggested that the rated Energy Factor for comparing HPWH performance with other technologies be applied; however, for a more conservative estimate an Energy Factor for HPWH of 80% to 90% the rated value may be assumed.

Some electric resistance backup should be expected from all units but particularly those where an upper thermostat is used to trigger backup electric resistance heat. The amount of backup can be minimized by using larger storage tanks. However, in retrofit situations this is not always possible. If the existing electric resistance water heater just meets the hot-water load during the peak 1 hour period, the HPWH will fall short during that 1 hour by the amount that its capacity is smaller than the capacity of the original electric resistance heater (nominally about 15,000 Btu/hr). Thus a 12,000 Btu/hr heater would fall short approximately 3,000 Btu of meeting the same load. However, individuals do not typically continue to consume hot water if there is none available, and more will likely restructure their consumption patterns.

An upper bound to the amount of backup resistance heat required can be understood by looking at the typical tank construction. In a typical electric resistance hot water tank, the upper thermostat is located approximately three-fourths of the way up the tank and will be typically set near 130°F. This means that the thermostat will shut off if the water temperature near it is 130°F or higher. It will signal for electric resistance heat approximately 30° below the thermostat setpoint, or when the water temperature at that level of the tank falls below 100°F. As hot water is drawn from the top of the tank, cool water flows into the bottom and there is a horizontal division between the hot and cold water in the tank. This division gradually rises up the tank during hot-water consumption. When the cool water rises to the level of the upper thermostat, it will signal the use of electric resistance backup. The hot water left in the tank above the thermostat setpoint can still be used. Thus, if a person runs out of hot water, the water in the upper 25% of the tank must be heated from essentially the supply temperature to the upper thermostat setpoint temperature before the upper element will shut off. This sets an upper limit on the amount of electric resistance backup that would be used during the peak period. This upper bound corresponds to about 5,000 Btu of hot-water energy for a 40-gallon tank, or about 12% of the DOE estimated level of daily hot water energy use for a family of four.

For a household that characteristically uses hot water till the water supplied is no longer hot, this sets a maximum bound for the amount of backup energy that will be used during the daily peak. Actual backup heat usage may be substantially less, because the occupants will probably not use all the available hot water every day. Installation of the next larger standard tank size (40-, 52-, 66-, 82-gallon) will offset some of the need for electric resistance backup; however in the Bonneville study, the average electric resistance backup energy was still between 1% and 2% of the daily hot-water energy use.

It is recommended here that if the tank used is smaller than the manufacturer recommends for the given family size, and if the HPWH is configured to use backup electric resistance heat, that the fraction of the load met by backup heat be estimated from the following equation

FLR = Tank Size (gal) x 0.25 x 8.28 Btu/gal-F x (135°F - CW supply temperature) x 25% / Daily Hot Water Energy Load (Btu/day)

where FLR = fraction of load met by resistance heat.

The 25% figure is included as simply an estimate of the frequency of running out of hot water on any particular day.

It is recommended here that if the installed HPWH be configured to use backup electric heat for faster recovery, the fraction of the load by the HPWH and by the electric backup should be estimated as above, and that the in-use energy factor be determined by weighting the fraction of load served by the efficiency of the heating mechanism (100% for electric resistance).

Step 5) Estimate Annual Hot-water Heater Energy Use. The following equation can be used to estimate annual electric resistance or hot-water heater energy requirements from the hot-water load calculated previously:

*Annual Hot-water Heater Energy (kWh/yr) = [Daily Hot-water Load (Btu/day) * 365 days/yr] / (EF * 3412 Btu/kWh)*

Step 6) Estimate Electric Demand. If there is a separate demand charge, determine whether savings from HPWHs occur at the same time as the demand peak. In general, residential water heater demand loads are highest between the hours of 6 and 9 a.m., are moderate during the rest of the day, and are very low at night. A good approximation of the afternoon demand from an electric water heater is the average kW draw during the day. This can be calculated as

Average kW = Daily Hot-water Load (Btu/day)/(24 hours x EF x 3412 Btu/kWh)

If the electrical demand peak occurs in the early morning hours, consider a detailed look at the effect of residential HPWHs on electrical demand. A local utility who has looked at water heaters may be a source for this information. In this case, the maximum demand that could be seen is the connected load of the water heater. Connected loads for electric resistance water heaters are typically 4,500 W. Connected loads for HPWHs can be obtained from manufacturers' literature. Note that a "quick recovery" configuration may use electric resistance heat during periods of peak hot-water usage and that this will increase the power draw of the HPWH.

Step 7) Determine Space Cooling and Heating Impact. Cooling benefits from residential ambient-air HPWHs typically come from the fraction of HPWH usage for afternoon and evening hot-water loads and tank standby losses. Because there are only two energy sources for the HPWH, the electric energy supplied and the heat extracted from the ambient air, the total cooling provided from a residential HPWH can be estimated from an energy balance on the hot-water tank as

Total Cooling (Btu/day) = Hot-water Load (Btu/day) x (1-1/EF)

The net cooling from switching from an electric resistance water heater to an ambient-air HPWH is somewhat larger than this because, in contrast to an HPWH, an electric resistance water heater actually heats the residence through tank losses. In an ambient HPWH design, where the HPWH is cooling the same space the HPWH is in, most of the heat lost through the tank walls is recovered by the HPWH. In an exhaust HPWH design this would not be the case, however.

Some of this net cooling will occur during periods when space cooling is required by the residence and will be beneficial to the residence. Some will occur during periods when space heating is required by the residence and will be detrimental to the residence. If one assumes that heating is required whenever the outdoor air temperature is below 65°F and that space cooling is required whenever the hourly temperature is above some higher temperature, one can quickly estimate the annual heating or cooling hours and determine the fraction of beneficial cooling or detrimental heating due to the HPWH.

In humid climates, many people use air-conditioning when the outside temperature is 65°F or higher, often simply to dehumidify a residence (which can also be accomplished with the HPWH). In mild and/or dry climates, many people do not air-condition until the temperature is considerably warmer than 65°F, often as high as 80°F, and many prefer to use natural ventilation for air temperatures between 65°F and 80°F. It is recommended that a diversity factor (DF) be applied to the space cooling calculations to account for the fraction of people who do not use air-conditioning until the outside temperature exceeds 80°F. Although no data are available, a diversity factor suggested here is calculated as

DF = [A x HR65 + (1-A) x HR80] / HR65

where A = 2 x (Design 2.5% Twb / Design 2.5% Tdb) - 0.9; HR65 = Annual hours with outdoor temperature greater than 65°F; HR80 = Annual hours with outdoor temperature greater than 80°F.

The combination of the DF, the heating and cooling periods, and factoring in the tank losses from the electric resistance water heater leads to the following equations for the effect on space conditioning requirements:

Annual Beneficial Space Cooling (BTU)= DF x HR65 x HW load (Btu/day)/(24 hr/day) x $(1/EF_{res} - 1/EF_{HPWH})$

Annual Detrimental Space Cooling (BTU) = (8760-HR65) x HW load (Btu/day)/(24 hrs/day) x $(1/EF_{res} - 1/EF_{HPWH})$

where HR65 = Annual hours with outdoor temperature greater than 65°F.

Weather Data information is available in "Engineering Weather Data" (1978), a combined armed services publication.

It is recommended that if the HPWH will be extracting heat from an unconditioned basement, the annual beneficial and annual detrimental space conditioning calculated be reduced by 50%.

The impact of the cooling on space conditioning energy requirements depends on the location of the air from which the HPWH transfers heat. If the air eventually comes from a conditioned space, then 100% of the space cooling described above impacts the energy use of the space-conditioning system. Note that the impact on space-conditioning loads of an exhaust-air HPWH is minimal for most climates, particularly if mechanical ventilation would normally be required for the residence.

The energy impact associated with HPWH space cooling requires knowledge of the space-conditioning equipment efficiency. Use the known SEER rating for the existing equipment if available; for heat pumps and air-conditioners, a typical SEER of 9.0 is a good default.

Typical heating efficiencies are 0.293 W/Btu for electric resistance, 14.2 therms/million Btu for gas furnaces, and a Heating Seasonal Performance Factor (HSPF) of 6.5 W/Btu for residential heat pumps.

If an exhaust-air heat pump water heater is used in a tightly constructed residence to improve ventilation, then there will likely be minimal impact on space heating or cooling loads and step 6 can be ignored.

Step 7) Determine Life-Cycle Cost. The energy use and cost data described previously can be used in the NIST Building Life-Cycle Cost program (BLCC) to estimate life-cycle cost for the HPWH and for continued use of the electric resistance water heaters.

Case Study

The following hypothetical study outlines steps needed to determine the cost-effectiveness of residential HPWHs. A hypothetical study was used here to help illustrate the impact of an ambient air HPWH (the most common available in the U.S. market) on residential space-conditioning loads.

Facility Description

A military base in central California is investigating the use of ambient-air HPWHs in residential housing. Typically the residences are single-story duplexes. According to housing statistics, there is an average of 3.3 persons per residence. Most of the residences presently have electric resistance water tanks that were installed in the late 1980s. The base wants to look at the use of ambient-air HPWH retrofits.

Avoided electrical energy costs for the residential areas on base are $0.059/kWh. Demand charges are $7.85/kW-mo. Because of the location, the peak electrical load is due to summer air-conditioning and occurs in the afternoon.

Existing Technology Description

Data on the EF of all water heaters on base do not exist. Most were installed in the late 1980s and will probably need replacement within 5 years. It is assumed that the average Energy Factor of an electric resistance water heater will be 0.85 over the analysis period. Existing water tank sizes vary between 40 and 52 gallons. An average size of 46 gallons will be assumed for this analysis.

Technology Being Considered

The technology being considered is add-on, ambient-air HPWHs as retrofits to the existing electric water heaters, which will be used primarily as storage tanks with the existing electric resistance elements used for backup heating. The EF of the HPWH systems considered is 2.6, with a nominal capacity of 6,000 Btu/hr. According to the manufacturer, the recommended minimum tank size for a 3 to 4 person family is between 52 and 66 gallons with this HPWH. Since the existing tanks are a bit smaller than recommended, the HPWH will likely require some electric resistance heat to supplement the load.

Estimates from HPWH suppliers have pointed to an installed cost of $985 for each water heater.

Procedure Leading to Evaluation

Data needed for evaluation are shown on the worksheet in Appendix C. It is estimated that the addition of an HPWH to each residence will increase the annual maintenance costs on base by $30.00/residence (based on 2.0 hrs/year times $15/hr labor). The life of the HPWH is estimated at 10 years.

A review of the weather data for the site ("Engineering Weather Data," 1978) suggests that there are 3,279 hours during the year with ambient temperature above 65°F, 1,309 hours during the year with ambient temperature above 80°F, and 5,481 hours during the year with ambient temperature below 65°F. The summer design 2.5% dry bulb temperature is 100°F. The summer design 2.5% wet bulb temperature is 71°F. From the list of nearby cities in Appendix B, the average water temperature is estimated to be 70°F. All residences presently use heat pumps for space-conditioning. The typical heat pump has an air-conditioning SEER rating of 9.35 and a heat pump HSPF of 6.5.

From the worksheet, the daily hot water load usage is estimated as 56.8 gal/day (equation 1). The daily hot water energy load is estimated as 30,575 Btu (equation 2).

Because the existing water heater tank will be used, supplemental electric resistance heat is anticipated. The Rated Energy Factor is modified as per equation (3b). Since the average tank size is estimated to be 46 gallons, the fraction of the daily load served by electric resistance backup is estimated to be 5.1%. The in-use EF for the HPWH is estimated in equation 3b to be 2.52.

From the worksheet, the annual hot-water energy use for the electric resistance water heater is calculated to be 3847 kWh/yr (equation 4).

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NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS

BASE CASE: ELECRES(a)
ALTERNATIVE: HPWH(b)

PRINCIPAL STUDY PARAMETERS:
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ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD:          10 YEARS (1995 THROUGH 2004)
DISCOUNT RATE:   3.0% Real (exclusive of general inflation)
BASE CASE LCC FILE:   ELECRES.LCC
ALTERNATIVE LCC FILE:  HPWH.LCC

        COMPARISON OF PRESENT-VALUE COSTS

                                     BASE CASE:    ALTERNATIVE:     SAVINGS
                                     ELECRES       HPWH             FROM ALT.
INITIAL INVESTMENT ITEM(S):          ----------    ------------     ----------
 CASH REQUIREMENTS AS OF OCCUPANCY          $0            $985          -$985
                                     ---------     ---------        ---------
     SUBTOTAL                               $0            $985          -$985
FUTURE COST ITEMS:
 ANNUAL AND NON-AN. RECURRING COSTS         $0            $260          -$260
 ENERGY EXPENDITURES                    $2,329          $1,143         $1,186
                                     ---------     ---------        ---------
     SUBTOTAL                           $2,329          $1,403           $926
                                     ---------     ---------        ---------
   TOTAL P.V. LIFE-CYCLE COST           $2,329          $2,388           -$59

     NET SAVINGS FROM PROJECT GSHP COMPARED TO PROJECT ASHP

      Net Savings  =  P.V. of non-investment savings         $926
                   -  Increased total investment             $985
                                                        -------------
                                     Net Savings:            -$59

               SAVINGS-TO-INVESTMENT RATIO (SIR)
           FOR PROJECT HPWH COMPARED TO PROJECT ELECRES

                   P.V. of non-investment savings
         SIR  =  --------------------------------  =  0.94
                   Increased total investment

              ADJUSTED INTERNAL RATE OF RETURN (AIRR)
   FOR ALTERNATIVE HPWH COMPARED TO ALTERNATIVE ELECTRIC RESISTAnCE
         (Reinvestment rate =  3.00%; Study period = 15 years)

                          AIRR =  2.37%

                   ESTIMATED YEARS TO PAYBACK
                  Simple Payback occurs in year 10
           Discounted Payback never occurs in study period

                       ENERGY SAVINGS SUMMARY
Energy         Units     ---Annual Consumption---      Energy
 type                     Base Case   Alternative      Savings
------------   -------   ----------   -----------    ----------
Electricity    kWh            3,847         1,888        19,590

 Note: the NS, SIR, and AIRR computations include differential capital
 replacement costs and resale value (if any) as investment costs, per
 NIST Handbook 135 (FEMP analysis only).
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(a) File name for electric resistance water heater (base case).
(b) File name for heat pump water heater alternative.

Fig. 6. Building Life Cycle Cost (BLCC) Output

The expected annual energy use for the heat pump water heater is calculated to be 1297 kWh/yr (equation 5).

Using the available weather data, a diversity factor of DF = 0.71 is calculated (equation 6) and from the hot-water load, the annual beneficial cooling is calculated to be 2,312 kBtu/yr (equation 7). The annual detrimental space cooling is calculated to be 5,444 kBtu/yr (equation 8). When the space-conditioning efficiencies are taken into account, the annual beneficial cooling energy savings calculated (using equation 9) is 247 kWh/yr. The additional heat required from the heat pump adds an additional 837 kWh/yr of electrical usage (equation 10b).

From equation 11, the total annual electric energy requirements for the electric resistance water heater are 3,847 kWh/yr. The total annual electric energy requirements for the HPWH, including the impact on space heating loads, is 1,888 kWh/yr (equation 12). In this example, the HPWH reduced the residence energy consumption by 51% when the effect on the space-conditioning energy was taken into account.

From utility data, the estimated contribution of the electrical demand for the electric resistance water heater is 5.27 kW-mo/yr (equation 13). The estimated electrical demand for the HPWH is 2.59 kW-mo/yr (equation 14).

The life-cycle costs for the electric resistance heat alternative and the HPWH alternative are calculated using the NIST Building Life Cycle Cost (BLCC) program. Since this was a retrofit example, costs for electric storage tanks were assumed identical for both alternatives and did not figure into the analysis. The resulting life-cycle costs from this analysis were $2,329 for the electric resistance water heater and $2,388 for the HPWH (see Figure 6). In this location and with these assumptions, the HPWH alternative was not cost-effective, costing $59 more over the life of each unit as compared with the electric resistance water heater.

Repeating the same analysis for a family of four persons in the same location resulted in a net life-cycle cost savings of $244. Other analysis results carried out for different locations and family sizes and assuming average Federal energy costs for these locations are shown in Table 3. As can be seen by these examples, there are locations in the United States where residential, ambient air HPWHs can be cost-effective in Federal sites; however, they typically depend on high energy costs or warm climates.

Table 3. Example Life-Cycle Cost Savings for Ambient Air HPWH

Location	Average Federal Electricity Cost ($/kWh)	Family Size (persons)	Net Life Cycle Cost Savings for HPWH
Fort Lauderdale, FL	$0.049	3	-$83
San Diego, CA	$0.096	3	$142
Honolulu, HI, without air-conditioning	$0.078	3	$195
Honolulu, HI, with air-conditioning	$0.078	3	$655
Birmingham, AL	$0.048	4	-$193
Niagara Falls, NY	$0.053	4	-$84
Baltimore, MD	$0.052	4	-$27
New Orleans, LA	$0.048	4	$66
Fort Lauderdale, FL	$0.049	4	$152

The Technology in Perspective

The future of residential HPWH technology in the Federal sector is uncertain. Although the technology is technically valid and can save substantial energy, lower-than-average residential electric energy costs, high first costs for HPWHs, and high maintenance costs in the Federal sector make residential HPWHs uneconomical in many, but not all circumstances. In addition, problems with early models continue to give HPWH a bad reputation at many Federal sites. Potential applications of HPWHs need to be carefully screened to determine the effect not only on net residential energy use but on maintenance workloads.

The Technology's Development

The residential HPWH technology is only beginning to reemerge as a viable alternative to electric resistance water heating. New products are coming into the market, but only from a few manufacturers, and the newest products are only beginning to be field tested. The efficiency of HPWHs has been improved, and new designs offer some flexibility to deal with issues of low capacity. What has not been conclusively demonstrated is significant improvements in long-term reliability of new models, and this will take several years. Although present day, cost-effective applications do exist, they depend on either high energy costs and low space heating requirements or a need for mechanical ventilation and heat recovery in cold climates.

Relation to Other Technologies

Two water heating technologies are closely related to the residential HPWH. These are 1) hot-water desuperheaters for air-conditioners and space-conditioning heat pumps, and 2) integrated heat pump systems.

The hot-water desuperheater is a hot refrigerant-to-water heat exchanger. It is an aftermarket device to be installed, after the compressor but before the condenser, in the refrigerant path of an air-conditioner or space-conditioning heat pump. This heat exchanger removes the superheat from the refrigerant vapor before it reaches the condenser and transfers that heat to the domestic hot water. Desuperheaters have been used successfully for decades in residential housing. Since desuperheaters only heat water when the air-conditioner or heat pump compressor operates, electric elements are still used when the hot-water load does not occur concurrently with the space-conditioning load. Desuperheaters typically meet 20 to 40% of a residence's water heating requirements (Caneta Research 1993a), depending on air-conditioning usage. Since desuperheaters typically have only two major components, a heat exchanger and a water pump, they require relatively little maintenance. Their effect on the air-conditioner or heat pump to which they are connected is typically a small improvement in cooling efficiency and a decrease in heat pump heating capacity.

Integrated heat pumps combine space-conditioning and water-heating heat pumps in one system. Thus a single package system is responsible for residential space heating, space cooling and hot water. Typically, water heating is accomplished using a desuperheater, or sometimes a separate condenser for water heating only. The latter system allows water heating to occur regardless of space-conditioning loads, since the compressed refrigerant can be cycled to the water heater condenser only.

Several manufacturers currently market integrated heat pumps. They are more complex and more expensive than heat pumps that provide only space conditioning; they are, however, a fast-growing segment of the residential heat pump market in both United States and Japan.

Technology Outlook

The use of residential HPWH technology in the Federal sector will likely move in parallel with adoption of the technology in the private sector. Although longer payback periods can often be supported in the Federal sector, costs for regular maintenance activities and lower electrical energy costs available in the Federal sector reduce the annual cost savings for this technology compared with its use in the private sector. In addition, negative prior experience with early residential HPWH models at many Federal sites may be difficult for manufacturers to overcome. The technology will continue to make inroads in the Federal sector in areas where gas is not available, where electrical energy prices are high, and where a second purpose (high space cooling or mechanical ventilation with heat recovery) can be effectively served by the HPWHs.

In March 1994, the DOE proposed an efficiency standard that would effectively ban the use of electric resistance water heaters in residential applications. Although the status of that proposal is uncertain, it has generated vast amounts of discussion regarding the use of HPWHs for residential applications. In general, most of the discussion has focused on flaws in the analysis leading to the DOE proposal. Criticisms (Little 1994) are that the economic analysis underestimated the cost for residential HPWHs, underestimated the cost for installation, and ignored the impact on residential heating loads. Other responses were that the manufacturing base did not exist to meet the production needs for HPWHs in this country by the proposed adoption date and that the hot-water energy requirements used in the study were higher than is typical in present-day residences. Although it appears unlikely that the DOE proposal will be adopted in its present form, the interest generated will probably continue to spur development of interest in HPWH technology.

In the future, there are two possible scenarios for residential HPWH technology. The first will be product-driven. For HPWHs to make a significant impact in the Federal sector will require the development and field testing of low-cost, reliable HPWH models to convince the Federal sector that the technology has matured and can be cost-effective. Until that occurs, the adoption of Federal-sector HPWHs will probably be limited to locations where high energy costs (greater than $0.07/kWh) and either low space-heating requirements or the use of heat pumps for space heating combine to make residential HPWH cost-effective in the private sector. The second possible scenario is that Federal rulemaking will mandate the use of HPWHs in all residential applications in the near future. In the latter case, it is important that Federal energy managers understand the technology in order to optimize its use at their sites.

Suppliers

There are presently two U.S. manufacturers of residential HPWHs. These are listed below. There are also several European and Japanese manufacturers of residential HPWHs and similar technologies; however, none of these products are presently marketed in the United States.

CRISPAIRE/E-TECH
Crispaire Corporation
3570 American Drive
Atlanta, GA 30341
David Shuford
Vice President - Marketing
(404) 458-6643; Fax (404) 457-2352

DEC/Therma-Stor
P.O. Box 8050
Madison, WI 53708
Bernie Mittelstaedt
(800) 533-7533; Fax (608) 222-1447

In addition, the following manufacturers are developing new residential/light commercial HPWH products that are scheduled to be released between late 1995 to early 1996 time frame:

Colmac Coil Manufacturing Co.
P.O. Box 72
370 N. Lincoln
Colville, WA 99114
Bruce Nelson, Vice President
(509) 684-2595; Fax (509) 684-8331

WaterFurnace International
9000 Conservation Way
Fort Wayne, IN 46809
Bob Brown
(219) 478-5667 ext 254;
Fax (219) 478-3029

Who is Using the Technology

The list below includes Federal-sector contacts, agencies, and locations that have experience with residential HPWHs. In particular, many of the contacts are familiar with the technology and also have been exposed first-hand to the maintenance issues. The BPA, as well as many regional utilities, continue to field test different models of residential HPWHs as part of its demand-side management/energy conservation programs.

Pearl Harbor Naval Base, HI
P.O. Box 110
Pearl Harbor, HI 96860-5020
Ken Perreira, Public Works Center
Energy Conservation Branch Manager
(808) 471-9065

Aliamanu Military Reservation, HI
Ken Perreira, Public Works Center
Energy Conservation Branch Manager
(808) 471-9065

Hickam AFB, HI 96853-5328
Bryan Young (808) 448-2350
James Taylor (808 449-7270

Robins AFB
Robins AFB, GA 31098-5000
Roy Locke, Base Energy Manager
(912) 926-6341
Bobbie Cantrel - All Star Maintenance (912) 923-7979.

Columbus AFB
Columbus AFB, MISS 39710-7901
Tom Wahler, Base Energy Manager
(601) 434-7403

MCAS Kaneouhe Bay
P.O. Box 63002
MCBH Kaneouhe Bay, HI 96863-3002
Wayne Lee (808) 257-2876

Bonneville Power Administration (BPA)
P.O. Box 3621
Portland, OR 97208-3621
Mark Jackson (503) 230-5475

For Further Information

User and Third-Party Field and Lab Test Reports

*Bonneville Power Administration (BPA), 1994. *Final Report Exhaust Air Heat Pump Monitoring Study.*

*Bonneville Power Administration (BPA), 1995. *Final Report for the IDWR Exhaust Air Heat Pump Study Phase 2.*

*Towill, 1988a. *Final Report Operational/Environmental Report on Hot Water Heat Pumps At Hickam AFB.*

*Towill, 1988b. *Final Report Operational/Environmental Report on Hot Water Heat Pumps At Aliamanu Military Reservation.*

Manufacturers' Application Notes

Crispaire Corporation. 1994. Four fliers about heat pump water heaters Products. Crispaire Corporation, Atlanta, Georgia
- E-Tech Heat Pump Water Heater Model B108K2 .
- E-Tech Heat Pump Water Heater Model R106K2 (tank-mounted).
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Appendixes

Appendix A: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix B: Data Sheet for Evaluating Potential Ambient-Air Heat Pump Water Heater Application

Appendix C: Data and Evaluation Sheet for Case Study

Appendix D: Cold Water Inlet Temperatures for Selected U.S. Locations

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Appendix A

Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 566-2877.

Appendix B

Data and Evaluation Sheet for HPWH

Energy Cost Data
Avoided Electrical Energy Cost ($/kWh) _______
Avoided Electrical Demand Cost ($/kW-Mo) _______
Daily Peak Demand Period _______

Hot-water Load Estimates
Number of Occupants per residence _______
Inlet Water Temperature (°F) _______

Existing Electric Water Heater Data
Year Installed _______
Energy Factor EF_{res} (Actual or Estimated) _______

Space Conditioning Data
Climate (Warm/Cool)
Summer 2.5% Drybulb Temperature _______ °F
Summer 2.5% Wetbulb Temperature _______ °F
Annual Hours with ambient temperature > 80°F _______
Annual Hours with ambient temperature > 65°F _______
Annual Hours with ambient temperature < 65°F _______

Air Conditioning (Yes/No)_______ SEER (actual or estimated) _______
Space Heating (Yes/No)_______
Space Heating Type _______
  Gas-Furnace EFF _______
  Electric Resistance-EFF _______ (nominal 3.413 Btu/W)
  Heat Pump-HSPF _______ Btu/W

Water Heater Cost Data

	Heat Pump Water Heater	Electric Resistance Water Heater
Base Cost ($)	____________	____________
Installation Cost ($)	____________	____________
Total Cost ($)	____________	____________
Annual Maintenance Cost ($)	____________	____________
Other Recurring Cost ($/interval)	____________	____________
Estimated Life Time (yrs)	____________	____________

Calculations
("eq" followed by individual numbers in brackets refer to results of the equation identified by the number)

(1) Hot-water Usage Estimate (Number of Occupants -1) x 10.7 gal/day/occupant + 32.2 gal/day) _______ gal/day
(2) Daily Hot-water Energy Load = 8.28 Btu/gal x _______ gal/day x (135-CW supply temperature) _______ Btu/day

HPWH EF
If supplemental electric resistance heat not anticipated
(3a) $EF_{hpwh} = EF_{rated}$

If supplemental electric resistance heat anticipated
(3b) $EF_{hpwh} = EF_{rated} \times (1 - FLR) + FLR$

Where FLR = Tank Size (gal) x 0.25 x 8.28 Btu/gal-°F x (135°F - CW supply temperature) x 25%/(eq2)

Annual Hot-water Energy Requirements

$$\textit{Annual Electric Energy} = \frac{\textit{Hot Water Energy Load (Btu/day)}}{\textit{Water Heater EF}} \times \frac{\textit{365 days/yr}}{\textit{3413 Btu/kWh}}$$

(4) Electric Resistance Water Heater _______ kWh/yr
(5) Heat Pump Water Heater _______ kWh/yr

Annual Space conditioning effect of ambient-air HPWHs

(6) DF = [A x HR65 + (1-A) x HR80)] / (HR65)

where A = 2 x (Design 2.5% T_{wb} °F/ Design 2.5% T_{db}°F) - 0.9
HR65 = number of hours per year with outdoor temperature > 65°F = _______ hr/yr
HR80 = number of hours per year with outdoor temperature > 80°F = _______ hr/yr

(7) Beneficial Space Cooling = DF x HR65 x (eq2) / 24 hr/day x ($1/EF_{res} - 1/EF_{hpwh}$) / 1000 = _______ kBtu/yr
(8) Detrimental Space Cooling = (8760-HR65) x (eq2) / 24 hr/day x ($1/EF_{res} - 1/EF_{hpwh}$) /1000 = _______ kBtu/yr

(9) Annual Space Cooling Energy Savings= (eq7)/(SEER) = _______ kWh/yr
(10) Annual Additional Space Heating Energy
(10a) Electric Resistance Heat= (eq8)/(3.413 kBtu/kWh) = _______ kWh/yr
(10b) Electric Heat Pump= (eq8)/HSPF kBtu/kWh) = _______ kWh/yr
(10c) Gas Heat= (eq8)/(EFF * 10) = _______ therms/yr

Annual Energy Requirements:
Electric Resistance Water Heater
(11) Electric Energy = (eq4) = _______ (kWh/yr

Heat Pump Water Heater
(12a)Electric Energy = (eq5) - (eq9) + (eq10a) + (eq10b) = _______ kWh/yr
(12b)Gas Energy = (eq10c) _______ therms/yr

Contribution to Demand (non-morning demand peak)
(13) Electric Resistance Water Heater Demand (kW) = (eq4) / 8760 hr/yr x 12 mo/yr = _______ kW-mo/yr
(14) HPWH Demand = (eq5) / 8760 hr/yr x 12 mo/yr = _______ kW-mo/yr

Appendix C

Data and Evaluation Sheet for Case Study

Energy Cost Data
Avoided Electrical Energy Cost ($/kWh) _$0.059_
Avoided Electrical Demand Cost ($/kW-Mo) _$7.85_
Daily Peak Demand Period _Afternoon_

Hot-water Load Estimates
Number of Occupants per residence _3.3_
Inlet Water Temperature (°F) _70°F_

Existing Electric Water Heater Data
Year Installed _Late 1980s_
Energy Factor EF_{res} (Actual or Estimated) _0.85_

Space Conditioning Data
Climate (Warm/Cool) _Warm_
Summer 2.5% Drybulb Temperature _100°F_
Summer 2.5% Wetbulb Temperature _71°F_
Annual Hours with ambient temperature > 80°F _1,309_
Annual Hours with ambient temperature > 65°F _3,279_
Annual Hours with ambient temperature < 65°F _5,481_

Air Conditioning (Yes/No) _Yes_ SEER (actual or estimated) _9.35 Btu/W_
Space Heating (Yes/No) _Yes_
Space Heating Type _Gas_
Gas-Furnace EFF____
Electric Resistance-EFF ___ (nominal 3.413 Btu/W)
Heat Pump-HSPF _6.5 Btu/W_

Water Heater Cost Data

	Heat Pump Water Heater	Electric Resistance Water Heater
Base Cost ($)	$600	$0
Installation Cost ($)	$385	$0
Total Cost ($)	$985	$0
Annual Maintenance Cost ($)	$ 30	$0
Other Recurring Cost ($/interval)	---	---
Estimated Life Time (yrs)	10	10

Calculations
("eq" followed by individual numbers in brackets refer to results of the equation identified by the number)

(1) Hot-water Usage Estimate (Number of Occupants -1) x 10.7 gal/day/occupant + 32.2 gal/day) 56.8 gal/day
(2) Daily Hot-water Energy Load = 8.28 Btu/gal-F x 56.8 gal/day x (135°F - 70°F) 30,575 Btu/day

HPWH EF
If supplemental electric resistance heat not anticipated
(3a) $EF_{hpwh} = EF_{rated}$

If supplemental electric resistance heat anticipated
(3b) $EF_{hpwh} = EF_{rated} \times (1 - FLR) + FLR$
$EF_{hpwh} = 2.6 \times (1 - 0.051) + 1 \times 0.051 = \underline{2.52}$
Where FLR = Tank Size (gal) x 0.25 x 8.28 Btu/gal-°F x (135°F - CW supply temperature) x 25% / (eq2)
FLR = (46 gal x 0.25 x 8.28 Btu/gal°F x (135°F -70°F)) x 20% / 30,575 Btu/day = 0.051

Annual Hot-water Energy Requirements
(4) Electric Resistance Water Heater 3,847 kWh/yr [(30,575 x 365)/(0.88 x 3413) = 3847]
(5) Heat Pump Water Heater 1,297 kWh/yr [(30,575 x 365)/(2.52 x 3413) = 1297]

Annual Space conditioning effect of ambient-air HPWHs
(6) DF = [A x HR65 + (1-A) x HR80)] / (HR65) = 0.71

where $A = 2 \times (\text{Design } 2.5\%\ T_{wb}\ [°F] / \text{Design } 2.5\%\ T_{db}\ [°F]) - 0.9 = \underline{0.52}$
HR65 = number of hours per year with outdoor temperature > 65°F = 3,279 hr
HR80 = number of hours per year with outdoor temperature > 80°F = 1,309 hr

(7) Beneficial Space Cooling = DF x HR65 x (eq2) / 24 hr/day x (1 / 0.85-1 / 2.52) / 1000 = 2,312 kBtu/yr
(8) Detrimental Space Cooling = (8760-HR65) x (eq2) / 24 hr/day x (1 / 0.85-1 / 2.52) /1000 = 5,444 kBtu/yr

(9) Annual Space Cooling Energy Savings= (eq7)/(SEER) = 247 kWh/yr
(10) Annual Additional Space Heating Energy
(10a) Electric Resistance Heat= (eq8)/(3.413 kBtu/kWh)____ kWh/yr
(10b) Electric Heat Pump= (eq8)/HSPF kBtu/kWh) = 837 kWh/yr
(10c) Gas Heat= (eq8)/(EFF * 10)____ therms/yr

Annual Energy Requirements:
Electric Resistance Water Heater
(11) Electric Energy = (eq4) = 3,847 (kWh/yr

Heat Pump Water Heater
(12a)Electric Energy = (eq5) - (eq9) + (eq10a) + (eq10b) = 1,888 kWh/yr
(12b)Gas Energy = (eq10c)____ therms/yr

Contribution to Demand (non-morning demand peak)
(13) Electric Resistance Water Heater Demand (kW) = (eq4) / 8760 x 12 mo/yr = 5.27 kW-mo/yr
(14) HPWH Demand = (eq5) / 8760 x x 12 mo/yr = 2.59 kW-mo/yr

Appendix D

Cold Water Inlet Temperatures for Selected U.S. Locations

Location	Avg. Cold Water Inlet Temperature (°F)	Location	Avg. Cold Water Inlet Temperature (°F)	Location	Avg. Cold Water Inlet Temperature (°F)
Anchorage, AK	38.6	Boston, MA	59.3	Rochester, NY	57.0
Birmingham, AL	71.7	Baltimore, MD	56.8	Rome, NY	51.3
Montgomery, AL	66.4	Portland, ME	63.5	Syracuse, NY	54.7
Little Rock, AR	63.9	Detroit, MI	49.9	Watertown, NY	51.7
Phoenix, AZ	82.3	Minneapolis, MN	45.8	Columbus, HO	54.8
Los Angeles, CA	72.8	Kansas, City, MO	51.1	Oklahoma City, OK	58.8
San Diego, CA	76.2	St. Louis, MO	61.3	Portland, OR	51.6
San Francisco, CA	67.7	Biloxi, MS	64.9	Philadelphia, PA	56.0
Denver, CO	61.3	Jackson, MS	67.8	Pittsburgh, PA	58.0
Hartfort, CT	56.6	Helena, MT	41.8	Providence, RI	49.7
Washington, DC	63.9	Raleigh, NC	71.8	Columbia, SC	59.2
Dover, DE	61.9	Bismark, ND	51.0	Sioux Falls, SD	55.3
Wilmington, DE	59.6	Lincoln, NE	53.5	Chattanooga, TN	67.7
Miami, FL	75.0	Concord, NH	65.6	Knoxville, TN	55.0
Tallahassee, FL	76.7	Trenton, NJ	55.3	Memphis, TN	55.0
Atlanta, GA	62.0	Alburquerque, NM	76.2	Dallas, TX	68.3
Savannah, GA	68.1	Carson City, NV	58.0	Houston, TX	65.9
Honolulu, HI	76.8	Albany, NY	51.5	Salt Lake City, UT	70.5
Des Moines, IA	60.3	Bingamton, NY	59.9	Richmond, VA	59.1
Boise, ID	45.3	Buffalo, NY	49.2	Montpelier, VT	47.8
Chicago, IL	53.9	Long Island, NY	53.0	Seattle, WA	41.1
Indianapolis, IN	49.0	New York, NY	57.6	Green Bay, WI	44.7
Topeka, KS	59.0	Plattsburgh, NY	50.6	Milwaukee, WI	46.0
Louisville, KY	56.3	Potsdam, NY	48.5	Charleston, WV	62.8
New Orleans, LA	64.9	Poughkeepsie, NY	56.8	Cheyenne, WY	51.7

Source: HOTCALC Commercial Water Heating Performance Simulation Tool, Ver 1.0 1991

About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of new energy-saving technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP, in a joint venture with the Department of Defense's Strategic Environmental Research and Development Program (SERDP), is sponsoring a series of Federal Technology Alerts (FTAs) that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $11 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

Strategic Environmental R&D Program

The Strategic Environmental Research and Development Program, SERDP, co-sponsor of these Federal Technology Alerts, was created by the National Defense Authorization Act of 1990 (Public Law 101-510). SERDP's primary purpose is to "address environmental matters of concern to the Department of Defense and the Department of Energy through support for basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." In 1993, SERDP made available additional funds to augment those of FEMP, for the purpose of new technology installations and evaluations.

FEMP
FEDERAL ENERGY MANAGEMENT PROGRAM

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